JUN 5 1924

MECHANICAL ENGINEERING

INCLUDING THE ENGINEERING INDEX

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To my mind there is no better basis for human work than study in engineering with its training in exact analysis, if you will also give the engineer a cultural training so that he knows something of the history of the development of a people, of its civilization, of its tendencies, and is fitted thereby to look upon these movements as they arise with some tolerance and also with sympathy.

GERARD SWOPE

(Substance of a statement in Aldred Lecture at M.I.T.)

JUNE 1924

THE MONTHLY JOURNAL PUBLISHED BY THE AMERICAN SOCIETY OF MECHANICAL ENGINEERS

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The Monthly Journal Published by

The American Society of Mechanical Engineers

Publication Office, 207 Church Street, Easton, Pa. Editorial and Advertising Departments at the Headquarters of the Society, 29 West Thirty-ninth Street, New York

Volume 46 June, 1924 Number 6

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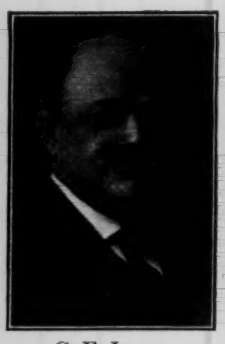
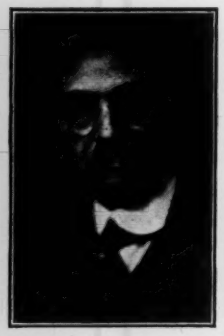
Price 60 Cents a Copy, $5.00 a year: to Members and Affiliates, 50 cents a Copy, $4.00 a year. Postage to Canada, 75 Cents Additional; to Foreign Countries $1.50 Additional. Changes of address should be sent to the Society Headquarters.

Entered as second-class matter at the Post Office at Easton, Pa., under the Act of March 3, 1879.
Acceptance for mailing at special rate of postage provided for in section 1103, Act of October 3, 1917, authorized on January 17, 1921.

J. A. HUNTER



C. E. LUCKE



A. L. DELEEUW

F. W. SPERR

M. R. DENISON

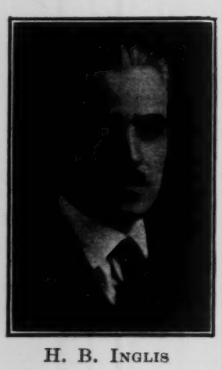
R. H. RAUSCH

Contributors to this Issue

A. H HOBLEY

A. H. Hobley and H. B. Inglis, co-authors of the paper on Aerial Bombing are both connected with the Army Air Service, Major Hobley as assistant chief of the Engineering Division and Mr. Inglis as a civilian engineer in charge of bombsight development, Engineering Division. Major Hobley was born in 1887 and is a West Point graduate, class of 1908. He organized and was the first commanding officer of the Armorers' School at Wilbur Wright Field and served for a time as assistant executive in armament and gunnery of the Division of Military Aeronautics. Previous to his present position, he was for three years chief of the Armament Section, Engineering Division, Army Air Service.

Mr. Inglis was born in Detroit in 1884 and received his B.S. in electrical engineering from Tufts College in 1906. His earlier positions were with the Westinghouse Electric and Manufacturing Company and the Detroit Edison Company. In 1917 he entered the Air Service, training in France for pursuit pilot. After many months of service there he was returned to the United States as "expert instructor in aerial-gunnery training, on temporary duty," and was commissioned Captain, A.S.A. Captain Inglis was transferred to the Engineering Division, Armament Section, in 1919 and honorably discharged the following year. Since then he has continued in charge of bomb-sight development as a civilian engineer. He is a member of the Inventions Board.



H. B. INGLIS

* * * * *

Charles Edward Lucke, whose paper on Value of Efficiency in Transforming and Distributing Energy appears in this issue, has been connected with the department of mechanical engineering of Columbia University since 1906, and the head of the department since 1908. Professor Lucke was born in New York City in 1876. He received his B.S. from the College of the City of New York in 1895, his M.S. from New York University in 1899, and his Ph.D. from Columbia in 1902. He served in the U. S. Navy during the war and is now on inactive duty with the rank of Commander, U.S.N.R.F.

* * * * *

John A. Hunter, author of the paper on the Generation and Utilization of Steam in the Iron and Steel Industry, was born in Kentucky in 1876. He was graduated from Centre College in 1896 with the degree of B.S. and in 1900 from Cornell University with the degree of M.E. After a year in the engineering department of the Bell Telephone Co., Mr. Hunter entered the employ of the American Steel and Wire Co. in Pittsburgh. Six years later he became associated with the American Sheet and Tin Plate Co., also in Pittsburgh, taking charge of the steam-engineering department. At present he is steam and sanitary engineer for that concern.

* * * * *

F. W. Sperr, the author of the paper in this issue on Practical Coal Carbonization, has been since 1915 chief chemist of the Koppers Co. in their laboratories in Mellon Institute. Mr. Sperr was born in Jefferson, Ohio. He was graduated from Ohio State University in 1906 and has been associated as chemist with the Illinois Steel Co., the Tennessee Coal, Iron and Railroad Co. and the Inland Steel Co. His principal work has been in the by-product coke and gas industries. He is Senior Advisory Fellow of the Coke Fellowship for the Mellon Institute.

* * * * *

A. L. DeLeeuw, author of the paper on Analysis of a Machine-Shop Problem on a Quantity and Final-Economy Basis, is a consulting engineer in New York City whose frequent contributions to the technical press on the development of manufacturing methods and equipment, and whose practical work in improvements in the machine-tool field have already introduced him to a large audience. Mr. DeLeeuw was born and educated in Holland, receiving degrees from both the University of Leyden and the Polytechnic at Delft. Among the important positions held in this country previous to his entering the consulting field are: chief engineer of the Niles Tool Works; chief engineer of the Cincinnati Milling Machine Co.; and chief engineer of the Singer Manufacturing Co.

* * * * *

M. R. Denison, makes a contribution to this issue on Material-Handling Problems Encountered in the Assembly of Automobiles which discusses time- and labor-saving methods devised for a modern automobile-manufacturing plant. Mr. Denison has been connected with the automobile industry for the past fourteen years, the first two of which were spent with the Metzger Motor Car Co. and the last twelve with the Studebaker Corporation. He assisted in the layout of equipment methods for the Studebaker plant erected in 1919 for the manufacture of light six-cylinder cars, and since the completion of the plant he has been superintendent of the stores division for the Studebaker Corporation.

* * * * *

E. H. McKitterick, presents a paper in this issue on the Relation of Mechanical Engineering to Management in the Textile Industry. Mr. McKitterick was born at Fort Sisseton, Dakota Territory, in 1889 and was graduated from the United States Naval Academy in 1912. He served in various capacities ashore and afloat until November, 1919, when he resigned from the Service. For the past four years he has been connected with Lockwood, Greene and Co., engineers and managers of textile plants of Boston.

* * * * *

R. H. Rausch, head of the production department and shop superintendent of the Niles-Bement-Pond Co. at Plainfield, New Jersey, describes the Sine Bar as a Universal Planing Gage in this issue. Mr. Rausch was graduated from Cornell University with the degree of M.E. in 1913. For two years after his graduation he was in the Bureau of Tests of the International Paper Co. Since 1915 he has been with the Niles-Bement-Pond Co.

MECHANICAL ENGINEERING

Volume 46 June, 1924 No. 6

Aerial Bombing

Early Practice and Conditions—Bombing Moving Targets—Theory of Bomb Trajectory—Principles of Various Sights—Ground-Speed Determination—Sources of Error and Methods of Overcoming Them

By MAJOR A. H. HOBLEY[1] and H. B. INGLIS,[2] DAYTON, OHIO

THERE is neither common sense, courage nor idealism in shrinking from the contemplation of the possibility of another war, nor in ignoring the terrific lessons of the war just past. One of these lessons is the importance of the part that aircraft will play. Another deduction, not so popularly apparent, is the overwhelming superiority of aerial bombardment as a destructive force over any other agency of the Army or Navy.

Bombing is the artillery fire of the air. But both in range and potency it far outstrips its sister of the ground. An aerial bomb can reach any target in enemy territory within flying distance of the airplane which carries it, a distance greater by several hundred miles than the longest-range gun or cannon. Its attack is more effective, since it carries a greater amount of explosive in proportion to its weight than any other missile. A 500-lb. bomb carries 250 lb. of explosives; a 1000-lb. bomb carries 500 lb.; while a 2000-lb. bomb carries 1000 lb. Comparison makes the amount carried by other missiles seem quite tame. For instance, a 16-in. armor-piercing cannon projectile, which weighs more than a ton, carries about 55 lb. of explosive; the submarine mines used for harbor defense, weighing from 1200 to 1700 lb., carry about 200 lb. of explosive; water torpedoes range from about 200 lb. of explosive in a 1500-lb. torpedo to about 700 lb. in a 3000-lb. torpedo.

Battleship *Virginia* Fifteen Seconds after Being Hit by an 1100-lb. Bomb

Bombing played a more important part in the World War than is generally realized. The aerial bomb knew no enemy front. Indeed, it is not the "front" with which the bomber is concerned so much as the weakening or destruction of the whole complicated organization behind the front. A continuous and systematic series of bombing attacks, directed against industrial, railroad, and other important centers, interferes seriously with those preparations which are vital to the successful operation of any army. In the World War not only was work completely held up in bombed cities from which basic supplies were drawn, but the morale and courage of the citizenry were completely undermined for weeks, and the soldier at the front, who feared nothing for himself, was utterly shaken at the rumor of harm to his family.

Aerial bombardment will undoubtedly, with the bombing of battleships, prove one of the important features of a future war. Reserve troops moving forward may be destroyed, troop trains may be blown up, and factories may be razed. Camps, railroad stations, bridges, arsenals, ammunition depots, supply trains, artillery on the march, fortifications, as well as aviation fields, with their airplanes and airships, all may fall under the annihilating blows of the aerial bomb.

The battleship, with its steel bulkheads, its steel protective decks, its armored hull, can be crippled and made helpless, and even actually sunk by a series of swift-descending bombs. Two-thousand-pound bombs were the largest used in the sinking of the battleships *New Jersey* and *Virginia* in September, 1923. It has been argued that these ships were not of the most modern construction, and were partly dismantled. But the destruction did not depend on penetration of the hull or deck, and it is the general conclusion from the sinking of ships by 1100-lb. bombs and their disabling by even smaller sizes that the heaviest, most modern battleship cannot withstand bombardment by the 4000-lb. bombs now available. It must be remembered, too, that the ship is carrying full steam pressure as well as magazines of explosives, and that even small bombs are a great menace, their concussion acting as a relay to the ship's self-destruction.

Early Practices and Conditions

Bombing first commenced at low altitudes, virtually in the nature of "ground attacks," by pursuit airplanes, supplementing machine-gun fire with the throwing overboard of steel darts, then hand grenades and small bombs. Ground attack is limited to comparatively small fast planes which can make an attack and a fast "getaway," so that for actual destruction it is not comparable to the power of thousands of pounds of explosives which can now be planted with great accuracy by large bombers from invisible heights. At low altitudes the skilful pilot can hold a direction toward the target closely enough by noting the apparent ground travel along the side of the fuselage, and crude sights were improvised in the form of a painted or two-nail line of sight at an angle ahead of the vertical, subtending a given "lead." This was fairly effective below 5000 ft., but when anti-aircraft forced the planes to go higher, such sights produced a period of "wild" bombing. The impression prevailed, and has not quite disappeared, that success was largely a matter of extraordinary aptitude of certain renowned members of a squadron, possessed of superhuman judgment. Not to detract from such practiced skill, a study of the bomb's trajectory soon revealed the fact that the differences in range for variation of air speed, wind, type of bomb, and ground speed were altogether too great

[1] Asst. Chief, Engineering Division, Army Air Service.

[2] In charge of Bomb Sight Design, Engineering Division, Army Air Service.

Contributed by the Aeronautic Division and presented at the Spring Meeting, Cleveland, Ohio, May 26 to 29, 1924, of The American Society of Mechanical Engineers. All papers are subject to revision.

and involved for any man to "guess" when to release the bomb, even at moderate altitudes.

The average accuracy of allied bombing progressively decreased from 73 per cent in 1915 to about 27 per cent in 1918. This was due largely to the fact that the instruments then in use produced an average dispersion of shots of roughly 5 deg., and while this subtends from 2000 ft. altitude an error of only 200 ft. on the ground, which was quite effective against large objectives, at 10,000 ft. the error became about 1000 ft., and the low percentage of hits considerably reduced the possibilities of accurate bombing. How effective bombing is today may best be judged by a perusal of results and conclusions.

It has been objected that anti-aircraft fire would have made the recent bombing tests impossible. The handicap which anti-aircraft imposes is perhaps best recognized by the flyers. In wartime the fliers were very quick to find out for themselves that level of operations known as "reasonably safe." All credit is due to the improvement in anti-aircraft guns, attaining a vertical range of over six miles, but the men who flew over the lines insist that the maximum range of anti-aircraft, or its increase, does not, per se, mean anything to them so long as the aim and control of the anti-aircraft burst in distance are ineffective at much lower altitudes Anti-aircraft could, during the last war, reach much higher than airplanes could fly, yet that fact was not alarming, even to those who knew it, for bombing continued with increasing volume on all sides in broad daylight at an average of 12,000 to 15,000 ft. altitude and at night from 400 to 1800 ft.

Improvement is being made in night pursuit, searchlights, and anti-aircraft, yet in the latter part of the war all of these defensive measures were quite well organized, with innumerable batteries of powerful searchlights and anti-aircraft provided with automatic interconnection which enabled concentration on the same point. Yet the difficulties in finding and aiming against airplanes, especially at night, remained out of all proportion to the advantage which the airplane has. The actual result was that more than fifteen hundred shots were spent to put a single airplane out of action, and this is a very conservative estimate. The bomber's ground objective is fixed or moving in two dimensions. The ground observer's target is a speck maneuvering and traveling fast in three dimensions, and it is far from a simple matter of instantaneous measurement and correction for the variables of gun fire involved. The location of the airplane in three dimensions and the gun-sight corrections for trajectory variations with elevation and range and for target speed present a somewhat more difficult problem for the ground gunner than vice versa. Even if the aim be brought to great accuracy and guns coördinate quickly, the timing of the explosion of the shot is alone a source of such variation as to render ineffective most of those shots which would otherwise be dangerously close.

The development of anti-aircraft tracers will undoubtedly improve the defense at low altitudes, yet fliers found that optical illusion rendered their tracer fire of no assistance beyond two or three hundred yards; and while anti-aircraft tracers may be seen at high altitudes,[1] perspective is lost, so that their proximity to the target is not measurable by the eye. Unquestionably anti-aircraft sights must be improved and combined with automatic setting of the gun, and the time of burst be brought under close control so that the average altitude of bombing will be raised; but so far the improvement of bomb sights in accuracy, in reduction of time exposed to anti-aircraft measurements, and in extension of altitude more than offsets the increase in anti-aircraft danger. One of the greatest advantages which the airplane has over the ground forces cannot be offset, namely, that about one-third of the time the character of the weather, visibility, and relative light contrasts enable the bomber to proceed almost with impunity at very low altitudes, when observation of the airplane is rendered null.

THE PROBLEM OF BOMBING MOVING TARGETS

The idea has been frequently advanced that the maneuvering of a ship at sea renders the accurate bombing of stationary, helpless, old ships inapplicable to wartime conditions. This conclusion is no longer warranted with the use of recent improvements. The only handicap which movement of the target now offers to the bomber is the few seconds of extra time necessary to establish a certain constant angle of approach. This angle depends upon the relative speed of target and airplane over the ground, neither of which the bomber need know. The establishing of this constant angle of approach against moving targets involves no extra operation on the bomber's part, and no knowledge on the part of either the pilot or bomber of direction or velocity of wind, ground travel, or target, nor of their relationship, as will be clear from Fig. 1.

The bomber at moderate altitudes can frequently see a ship at sea for 75 miles or more. He may approach the enemy from any direction which may be to his advantage, in avoiding pursuit, or under cover of the sun or clouds, up to within about $1\frac{1}{2}$ miles before he need align upon a constant angle of approach just long enough before bomb release to set the sight on a few seconds' straight line of approach CE. At any random position A the bomber's line of sight held on the target B moves laterally, until at C the pilot has been aligned by the bomber's signals so that lateral movement of the sight has ceased. It does not matter what may be the ship's speed DF, nor the bomber's ground speed CE, the wind W, nor their direction, since the sight measures the "relative speed of approach" along CD, EF, etc., and the bomb released at E will strike at O after the ship has traveled from F to O.

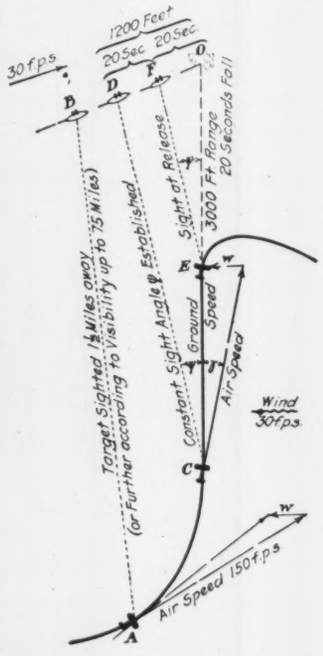


FIG. 1 COURSE IN BOMBING MOVING TARGETS

The enemy's one opportunity for careful anti-aircraft measurements of the airplane's speed, altitude, and direction is during his travel from D to F, while the bomber is holding a straight course from C to E—twenty seconds or less. Previous to the bomber's alignment at C and after bomb release at E, the airplane may maneuver, dive, or climb, constituting an exceedingly difficult target, while it is changing all three factors of its location during the sighting of the aircraft guns. During this time the enemy is attempting his sharpest maneuvers, so that his anti-aircraft measurements are badly handicapped by the ship's oscillations.

Now let us analyze the effect on bombing accuracy which target movement presents. Any maneuvering of the ship from D to F is met by correction of alignment by the bomber (the 20 sec. of flight from C to E allows a few spare seconds to realign over and above the time required to set the sight for range) and a partial or complete correction for the range EO, since the timing sight takes account of the average enemy speed from D to F and thus partly corrects for any change within that time, and a synchronous method sets the range for enemy speed existing at F, or the very instant of bomb release at E. It is superficially stated that the ship need only maneuver during the falling time of the bomb to escape the hit at O. What can the battleship actually do in that time? For the sake of argument let the bomber give the benefit of doubt to the enemy and climb to 20,000 ft., corresponding to a falling time of about 36 sec. It is a matter of engineering knowledge according to reference works on naval architecture that a first-class battleship cannot by any maneuvering get out of contact with its center line of motion FO (straight or tangent to a curve) in considerably more than that time; nor can it change its speed sufficiently to arrive short or over the hit. Thus with alignment and range methods for relative approach, the bomber can sight upon a moving target exactly as if it were fixed. The battleship's only real chance is that the bomber will make too large an error. The nature and amount of bombing errors and methods of correction will be briefly analyzed, after presenting the general problems.

It should be stated that fast, smaller, and highly maneuverable

[1] It has been stated unofficially that tracers are visible up to 7500 ft.

cruisers or destroyers do not offer so sure a mark for a single bomber, but they are nevertheless practically helpless in the face of bombardment as it is actually conducted in warfare, that is, by "flights" of three or more bombers in echelon formation, repeating in salvo, or each dropping a trail of two or more bombs spaced in range. With present accuracy, allowing for the average error in the centering of the group, there is no single ship which can escape the area of destruction covered by six bombs thus spread out.

Effectiveness of Bombing

"Effectiveness" in any arm does not of course require 100 per cent of "dead" hits. A "hit" prescribes a certain limit to the error according to the size of the objective and type of explosive suited to it.[1] Much less than 50 per cent of hits is of course decidedly effective in warfare.

The last war was overwhelmingly a battle between land and air forces, naval forces being largely engaged in the conduct of transport service, so that few data were available as to the effect of bombing ships, except that the average accuracy of wartime sights was there as dubious as it was on land, and the small-size bombs did not insure the sinking of a ship even by direct hits. That a 2000-lb. bomb does definitely put the strongest ship in existence out of action is the official conclusion of the joint Army and Navy Board after conclusive tests in 1921 against the *Ostfriedland*, which vessel was heavily armored to withstand torpedo attack. That the bomb may strike anywhere within 30 ft., of the ships' outline with as sure an effect or greater was also conclusively shown, but there is some question as to how much farther it is still effective. Wartime sights averaged roughly a radial error equivalent to roughly 5 deg. off the vertical. Most of the recent bombing on the *New Jersey* and *Virginia* was done with such sights, registering 20 per cent of effective hits from altitudes averaging about 6000 ft. Without pressing the point that the bombing of ships at sea can be conducted at 6000 ft. with no more risk than from 10,000 ft. on land, recent Air Service developments have accomplished better than 1 deg. average, with no limitation on direction of approach and with the cutting in half of the time of straight-flight exposure to anti-aircraft measurements. This obviously means that the same percentage of effectiveness could be attained at five times that altitude, or that at reasonably safe altitudes as 20,000 ft. the increased effectiveness of bombing is most formidable.

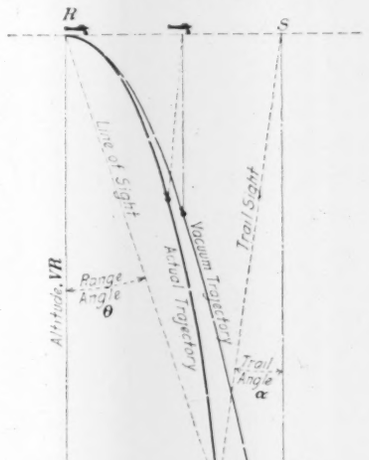


FIG. 2 ELEMENTS OF A BOMB TRAJECTORY

Theory of Bomb Trajectory

Neglecting air resistance, a bomb released at R (Fig. 2) from an airplane flying horizontally and at uniform speed toward S will follow the path RP. This path is a parabola tangent to the airplane at instant of release, and the bomb following it always appears vertically beneath the airplane from which it was released. The horizontal distances of points on this path are directly proportional to the corresponding times, while the vertical distances are proportional to the squares of the times. The horizontal component of the bomb's velocity is equal to its speed of release and is uniform, while the vertical component is uniformly increasing under gravity.

The air resistance encountered by a bomb falling under actual conditions considerably modifies the parabolic path and causes it to follow the curve RO. This resistance varies continuously during the bomb's flight, both in amount and direction. Its horizontal component reduces the bomb's forward velocity, thus causing it to fall behind the vertical from the airplane, while its vertical component retards the bomb's vertical motion. The net effect is to cause the bomb's actual path to fall behind its vacuum path and to increase its time of fall. The airplane's flight being assumed to be in the plane of the wind, the trajectory is in the vertical plane of projection.

The horizontal distance between the vacuum trajectory and the actual trajectory is called "air lag," or at the ground, "ground lag." The distance OP is the ground lag, or the distance the actual bomb strike the ground in the rear of the "vacuum bomb." The actual bomb, however, does not reach the ground until a certain time lag L_t after it would have struck the ground in a fall through vacuum. The actual time of fall T is then the sum of the time of fall T_v in vacuum and the time lag L_t, or $T = T_v + L_t$.

During the time lag the airplane (assuming it continues its horizontal motion at uniform speed) will travel the distance $PV' = G$ (ground speed $\times$ L_t). The vacuum bomb during this time would continue its fall and reach V_1' by the time the actual bomb struck the ground at O. The distance OV' that the actual bomb strikes the ground in rear of the vertical dropped from the airplane at the instant of impact is called the "trail" distance, and the angle OSV' subtended at the airplane by the "trail" is known as the "trail angle." The trail

$$OV' = OP + PV'$$
$$= L_g + G \times L_t$$

where L_g = ground lag
L_t = time lag
G = ground speed.

Since the airplane's travel VV' during the time the bomb is falling is $VV' = GT$, the true "range" of the bomb is $VO = GT -$ trail. This range distance represents the actual distance, measured on the ground, traveled by the bomb from its release in the airplane to its impact on the ground. The range angle θ subtended by the range distance establishes the line of sight in which the bomber must see the target at the instant of release.

$$\tan\theta = \frac{GT - \text{trail}}{H}$$

$$= \frac{GT}{H} - \frac{\text{trail}}{H}$$

$$= \frac{GT}{H} - \tan\alpha \text{ (trail angle)}$$

which is the fundamental equation for the range angle. The solution of this equation requires (1) the altitude H, which is obtained from the airplane altimeter; (2) the ground speed G, which must be found by the bomb sight; (3) the time of fall T, and (4) the trail angle α, the last two of which must be calculated and corrections provided for in the design of the bomb sight.

The trail of a bomb is due to its motion through the air and varies with this rate of motion and the type of bomb. Hence it varies with the air speed and is not at all affected by the wind velocity, provided the wind is of uniform velocity and direction during the entire time of fall. Since the air speed is in the direction of the airplane's longitudinal axis, the trail of a bomb is in the direction of this axis and in the vertical plane through it. The trail and trail angle vary in magnitude with

1 The type of bomb
2 The method of suspension
3 The airspeed at release
4 The altitude at release
5 The wind in the path of fall.

The type of bomb influences the trail angle by affecting the time of fall of the bomb and its horizontal lag. The vacuum speed of a bomb would continue to increase as long as it was allowed to fall, but air resistance increases with the speed of the bomb and ultimately reaches a value where it is equal to the weight of the bomb.

[1] The development of bombs from a few ounces to thousands of pounds each for specific effects upon different kinds of objectives, has not been simple. An excellent general description, by Major Borden, will be found in *Army Ordnance Journal*, January and February, 1923.

After this time no further acceleration occurs, and the bomb continues to fall with a uniform velocity. This velocity, known as the "terminal velocity," varies with the type of the bomb. Large bombs with a high ratio of weight to cross-sectional area have relatively low air resistance and therefore have a higher terminal velocity than smaller bombs. This velocity varies from approximately 900 ft. per sec. for the 100-lb. bomb to about 1700 ft. per sec. for the 2000-lb. bomb. Trail angle varies widely with bomb type, increasing rapidly as the terminal velocity decreases.

The American practice of suspending bombs with their long axes horizontal naturally involves less head resistance than vertical suspension. Vertical suspension would require complete recalcula-

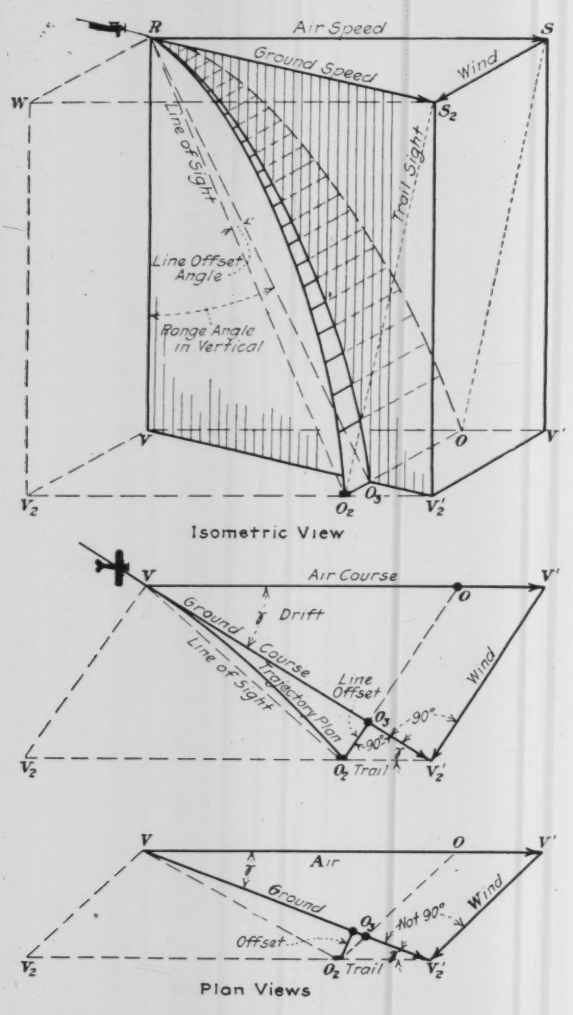


FIG. 3 BOMB TRAJECTORY IN A DRIFT COURSE

tion of trajectories for all bombs, but the tendency to wobble around the main trajectory would be so great that the advantage of more convenient storage in the fuselage is offset by erratic results.

Trail angle varies almost directly with air speed, but to so small a degree with altitude that its correction for altitude has been ignored heretofore, with very little error.

Wind in the path of fall alters the proportion of ground lag to the total trail, but the trail is independent of wind, being a function of air speed. Ground speed down wind is air speed plus wind, and up wind, air speed minus wind. Part of the trail is ground speed times time lag, and is greater down wind; conversely, the ground lag is less down wind. The ground lag becomes equal to the whole trail if the ground speed be zero, as in case of a hovering dirigible.

If instead of flying in the plane of the wind, as assumed above, the airplane flies a course in a cross-wind as shown in Fig. 3, the airplane actually travels in a vertical plane which intersects its air-speed heading at the "drift" angle. If RS represents the direction and speed of the airplane relative to the air and W be the wind relative to the ground, then the closing side of the vector triangle RS_2 will represent the ground speed in amount and direction. It should be noted that the airplane and any bomb dropped from it are moving laterally with the wind and at the same rate, and that there is no relative motion between bomb and wind. The falling bomb therefore meets axial resistance only and "trails" behind the airplane in the vertical plane through its longitudinal axis, exactly the same as when the flight is in the plane of the wind's direction. The trail O_2V_2' is equal and parallel to OV', the trail which would result had there been no cross-wind—or no wind at all. The range of the bomb in the actual direction of the ground course toward the target, is therefore $V_2'O_3$, which is equal to $V_2V_2' - V_2'O_2 \cos \gamma$. The range angle is then obtained as before, but provision must be made to alter the direction of the airplane's axis to correct for the drift angle and the effect of the trajectory from the ground course of the airplane.

PRINCIPLES OF THE VARIOUS SIGHTS

An error to the right or left of target is of course just as serious as one short or over in range, so that accurate means of alignment is quite as important as the determination of instant of release and should be incorporated in any bomb sight. The sight, commonly speaking, however, concerns the method and principle of determining the range angle of the line of sight, and some of these methods will be illustrated.

One of the simplest forms of sight comprises merely a line of sight, set to the range angle found in a book of tables under Ground Speed and Altitude (sometimes taking account of wind, with or against air speed, and type of bomb). The handicap to concentration is so great in wartime flight that such reference to tables is rarely productive of good results. Reference tables were dispensed with by setting the horizontal side of the triangle to a scale of ground speed and the vertical side to the average vertical speed of the bomb for the time of fall from a given altitude. If the top point of the line of sight was then set ahead of the vertical a distance proportional to the trail, the angle was correct. The general practice was to make such trail correction permanent for assumed usual combinations of air speed, terminal velocity, and altitude—instrumentally very inaccurate for variable conditions—or to provide adjustment for air speed only—a partial correction, but still not sufficiently accurate for high altitudes. The outstanding difference between bomb sights is in the methods and operations employed, to determine the most important ground-speed factor. Many ingenious schemes were evolved for determining true ground speed on the spot, and these may be generally classified as follows:

1 Drift method
2 Timing:
  a Over fixed ground distance
  b Over fixed angle
  c Over angle whose tangent is inversely proportional to the time of fall
3 Synchronizing (following the apparent ground travel with a movable member of the sight mechanism).

GROUND-SPEED DETERMINATION

Drift Method. Wimperis has devised an ingeniously simple means of determining ground speed by a drift method Referring to Fig. 4, the top wire is set back of vertical to an air-speed scale and flight is then directed 90 deg. across wind. By moving a drift bar on to the resultant ground course the vector triangle air speed, wind speed, and ground speed is thus established. The drift-bar side of the triangle not only subtends the wind velocity on the wind scale, at right angles to the air-speed bar, but this movement of the drift bar simultaneously sets two halves of the top wire, one ahead of the air-speed setting and the other behind, so that the one is used for down-wind approach set for air speed plus wind, and the other for up-wind approach set for the air speed minus the wind. This sight was used up to the end of the war for its advantage of simplicity, in spite of the fact that the maneuvering which is involved in any drift method of ground-speed determination that is practical for purposes of navigation offers too much handicap to time and attention in bombing, with the result that crews invariably resorted to guesswork, or weather predictions of wind, with consequent enormous errors in range. Thus a drift method is limited to very low altitudes, as under 5000 ft.

Timing Methods. Timing the apparent ground travel over a

fixed angle is one of the oldest methods of accurate ground-speed determination. Timing methods involve the use of a watch or clock mechanism. Personal errors of starting, stopping, reading a separate stop watch and resetting the bomb sight created prejudice against this method during the war, whereas criticism should have been applied to the particular application of the timing method. The British C. F. S. sight and the French ST Ae sight employ the following method. Referring to Fig. 5,

$$\text{Ground Speed } G = \frac{H \tan \theta}{t}$$

where t is the time for the target to pass across the angle θ, and H is the altitude. If the angle be made to vary according to tan θ = k/H, then $H \tan \theta = k$ and the ground speed $G = k/t$, where k is a constant. If the angle be made to vary as tan $\theta = k/T$, where T is actual falling time, then Ground Speed = kH/t and Time $t = kH/GT$, whence $\tan \theta = k/t = GT/H$.

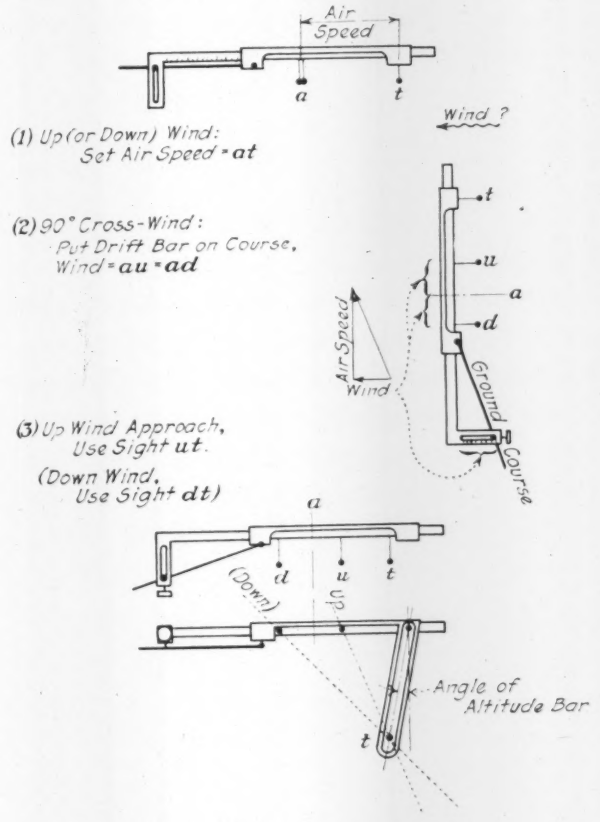


FIG. 4 WIMPERIS DRIFT PRINCIPLE

The range angle may be set up by observing the apparent travel of the ground over a fixed interval of time, then increasing this distance in the ratio of the time of fall to the timing interval. This method has the advantage of the possibility of automatic definition of the time interval.

Double-Distance or Equidistant Timing Method. In addition to the timing method, involving only two scales—altitude and time—but requiring the sighting on an auxiliary target previous to reaching the objective, the French ST Ae sight also provided for the "double-distance" method, which has the advantage now considered essential that it is applicable on the target itself (or an auxiliary target, as desired).

Referring to Fig. 6, two sight wires, x and y, are so linked by pantograph mechanism that wherever x is set ahead of the fixed trail post o' the sight xy bisects xo', that is, $xy = yo$, or the time t for the ground to move from x to y is the same as it is to move from y to o'. It is required that yo' be set for some distance greater than the actual range, so that the time t is something greater than the actual falling time T. Now, if a reversible chronometer is started at zero upon the intersection of the line of sight RX with the objective and reversed at RY, the pointer will get back to zero as the line RO' intersects the objective. A rider pointer is provided on the watch and is set ahead of zero the distance the watch pointer will cover during the falling time. (The scale is graduated in corresponding altitude.) Now, when the watch pointer—which was reversed as the line of sight Ry intersected the target—reaches the rider pointer corresponding to the intersection of RO with the target, the bomb is released. The bomb will fall for the time T, through the range $O'O$, which is correct for the ground speed thus measured.

Trail correction for time-lag variation with altitude could be made in the watch-scale graduation for altitude (time of fall), while partial correction for trail variation with air speed was provided in the air-speed setting of the top wire aR. The double-distance method was recommended for altitudes above 1000 meters and the first method for lower altitudes. The double-distance method can be used on an auxiliary target, if desired, by stopping the watch at Ry, and reversing it later when RY picks up the real

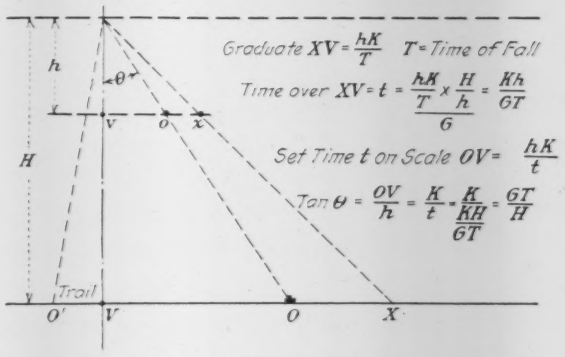


FIG. 5 C. F. S. TIMING SCALE

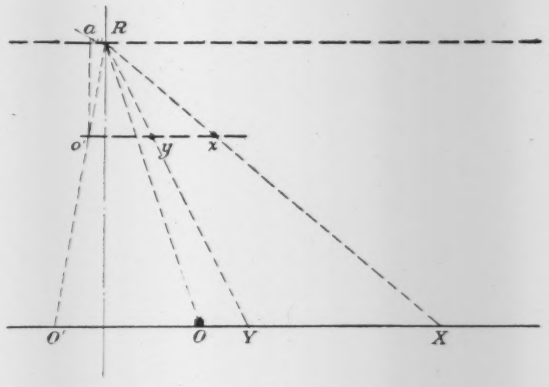


FIG. 6 DOUBLE-DISTANCE OR EQUIDISTANT TIMING METHOD

objective, provided of course the same line of approach is continued without change of ground speed.

Any method of ground-speed determination which necessitates the use of an auxiliary target involves a serious extension of the time required for straight approach and is, moreover, quite impractical for use at sea where there may be nothing to sight upon except the objective, unless a spotting shot or smoke bomb be employed.

Synchronous Methods. Synchronous methods of determining the ground speed (Fig. 7) by following the apparent ground travel with a moving part of the instrument have much in their favor, inasmuch as they may overcome the objections against timing methods and to manipulation of the watch, and because they may eliminate personal errors and the extra time involved in resetting data. The watch has, however, been applied in a timing method so that these operations are entirely automatic aside from starting it.

The relative disadvantage of the timing method is that it gives an average speed over a time interval, whereas the synchronous methods may give the speed at the instant of release. But timing over an interval may be of relative advantage if the synchronous system offers chance of an error at the instant of release, inasmuch as the whole ground-speed measurement may depend upon complete coördination at the last instant. A synchronous method has, however, been so applied in a recent Air Service development that momentary accelerations or decelerations due to violent airplane oscillations, which would give an apparent change of ground speed, are not recorded in the ground-speed measurement, while any

normal change of actual ground speed is taken care of. A synchronous method therefore still offers the advantage that the ground speed at the instant of release may be measured more accurately.

SOURCES OF ERROR

Air Service development has greatly reduced most of the following errors, and eliminated some of them.

Sources of error may be classified in the following order, which is in accord with the relative usual magnitude of the errors involved:

1 *Alignment* of the ground course of approach toward the objective, and its correction for the trail offset

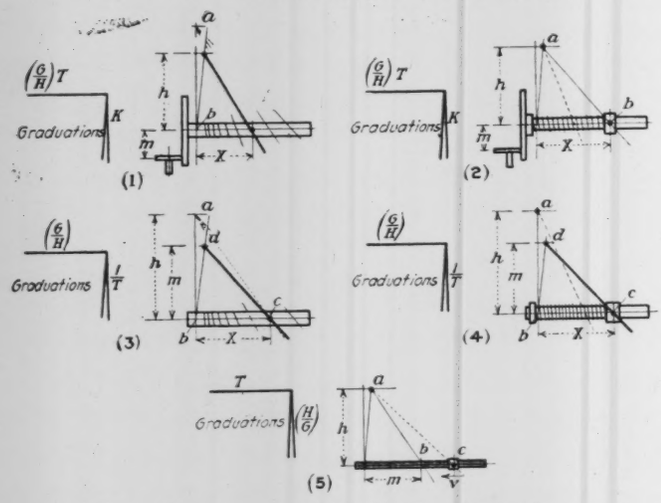


FIG. 7 SYNCHRONOUS TIMING METHODS

(1) Variable-Speed (Brown): Logarithmic screw, tangents intersect at a common point a and all points travel at a rate to reach b at the same time. Range angle is at the point of synchronous speed. Speed of rotation adjusted, as by m, so that the above time is equal to the time of fall T, or speed $= ab/vT$, and rate of travel of any point is $x/T = (h/H)G$. Tan $\theta = x/h = GT/H$.

(2) Variable-Speed (Brown): Similar to (1), excepting that an elastic screw is substituted for the logarithmic screw. Range angle given by ab. Speed of rotation adjusted as above by change of m, synchronizing on any part of screw by change of position of b. Range angle over ab.

(3) Constant-Speed (Brown): Logarithmic screw, tangents intersect at a common point a and all points travel at a rate to reach b at the same time. Sight over point a, determine point c moving in synchronism with ground. Range-angle sight over dc (one fixed). Set $m = kh/T$; $v = x/k = hG/H$, or $x = khG/H$. Tan $\theta = x/M = (khG/H) \div (kh/T) = GT/H$.

(4) Constant-Speed (Brown): Similar to (3), excepting that an elastic screw is substituted for the logarithmic screw. Range angle given by dc.

(5) Constant-Speed (Barr-Milne): Set $m = vT$. Synchronize by sight over ac with change of h. Range angle over ab. $v/h = G/H$, or $h = vH/G$. Tan $\theta = m/h = vT/(vH/G) = GT/H$.

2 *Range.* Instant of release, corresponding with intersection of target by line of sight at correct range angle.

- *a* Ground-speed determination and sources of lesser instrumental errors in determination of the range angle
- *b* Personal errors of time, observation, and definition of instant of release, in operation of the instrument and of release
- *c* Sources of errors independent of the sighting instrument itself; indeterminate variations from the normal trajectory for a given type of bomb; altimeter indication; air-speed indication; air density; change of wind during bomb's drop

3 *Oscillations,* affecting both alignment and range stabilization of the line of sight.

NOTE. As the basis for comparison of errors the following values will be taken, except as otherwise stated:

Altitude, 8000 ft. equivalent to falling time of approximately 23 sec.
Air speed, 100 miles per hr.
Ground speed, 100 ft. per sec. or 68 miles per hr.
Type of bomb, 100 ft. per sec. terminal velocity.

Alignment. Errors of alignment averaged greater than range errors not only with instruments like the Michelin, which is capable of accurate range determination by a timing method, but even with sights like the Wimperis, which is inherently inaccurate with drift method of ground-speed determination and roughly approximate trail correction. Most sights provided no means for accurate ground-speed determination on a drift course, and were consequently limited to approach up or down wind. Tactical handicaps and crude directing means resulted in an average drift error of roughly 10 deg.

EXAMPLE. A drift error of 10 deg. is not serious if the actual ground travel is in line to target, involving a small error of range with a timing method and with a drift method only 38 ft. error.

The chief error with crude direction devices, or frequently pilot's estimation, was in alignment of the drift course toward the objective. The impression is quite common that it should be rather easy to "fly vertically over" a ground object, or for bombing to have the ground course aligned at the instant of bomb release in the vertical plane passing through the objective. This fallacy is held not alone by the layman but is surprisingly prevalent among skilful pilots who have not flown for bombing at high altitudes. The following attempts to fly vertically over a recording camera obscura by estimation astonished five pilots who were chosen for flying skill hardly to be exceeded, choosing their own type of airplane, height, and direction in calm weather.

EXAMPLE. 25 trials from 2000 to 8000 ft. averaged 183 ft. off line per 1000 ft. altitude, or $10^1/_2$ deg. off the vertical. (The best were 2 deg. off and 90 per cent were over 5 deg. off.)

Five degrees is about the least that can be sensed by the eye or feeling. Five degrees subtends but 44 ft. from 5000 ft. altitude, where estimation of both line and range is often effective in the field of ground attack, but at 8000 ft. it subtends 700 ft. error; thus for bombing operations instrumental alignment is obviously indispensable.

EXAMPLE. If the actual ground course is 5 deg. off the target at instant of release, then for a range of, say, 2000 ft., the hit is off center 2000 × tan 5 deg., or 175 ft. Improved methods of stabilized alignment have averaged better than 1 deg., or 35 ft.

Alignment by compass bearing may be easily 5 deg. off. The earth inductor compass under development by the Engineering Division is accurate to within 1 deg. and precession of a gyro pilot director for the brief time of alignment is even less, so that by combining either of these with the bomber's direction of the pilot's ground course the line can be held with great accuracy between the bomber's corrections; and alignment is assured within the very small error of observing an indicator pointer, or better than the variation of the bomb's trajectory itself, for which the instrument is not responsible.

Trail Offset (See Fig. 3). It is often asked if a cross-wind does not "blow the bomb off its course." Assuming for the moment a constant wind, the trajectory in a drift course is warped to leeward, and this is mistaken as a windage after-effect on the bomb. The bomb when released has, like the airplane, the wind's velocity as a component of its ground course in the wind's direction. Nothing changes this component, while the bomb does lag in its direction through the air, decreasing this component so that the bomb lands to leeward of the airplane's ground track.

EXAMPLE. The trail direction is at the drift angle from the ground course, and the offset of the hit from the original ground track is the trail times the sine of the drift angle—in a 30-deg. drift, 165 ft. for the data assumed. Correction of alignment for this offset is made automatically with recent sights, as a function of drift angle and altitude, by offsetting the line of sight on an axis parallel to the ground course.

Change of wind during the bomb's fall will of course alter the line offset, not at all in direct proportion to such changes but only to a very small extent comparable to the change of lag in range as a function of the bomb's air speed.

Range Errors. Vector summation of air speed and wind involves a direct error in ground speed equal to the errors in wind and air speed.

EXAMPLE. An error of 5 miles an hour, easily exceeded in wind determination by a drift method, means a range error of 170 ft.

Error of indicated air speed is frequently as great, but with any method of ground-speed determination independent of wind or air speed this error of air-speed indication involves but a small difference in lag, as 7 ft.

A fixed trail correction for one set of conditions only is the source of large errors under other conditions.

EXAMPLES. If the trail correction is set for a 600 T V bomb, then the range error for a 1200 T V bomb is roughly 700 ft. for other data assumed.

Again, if the trail is corrected for an air speed of 75 miles per hour, an air speed of 100 miles per hour accounts for a range error of approximately 100 ft.

Personal Errors. Time error of delayed action in the release mechanism is negligible with modern racks. Personal delay in manual pull averages scarcely more than 0.2 sec., or a 29-ft. range error. Automatic release by the sight enables complete compensation for the smaller and constant lag.

A time error of 0.2 sec. in the observation of action in watch timing gives approximately a one-mile-per-hour error in ground speed, or a 34-ft. range error.

In an open wire sight a $^1/_{32}$-in. wire 12 in. from the eye subtends 250 ft. on the ground from 8000 ft. elevation. Observation of edges actually produces better results than that, yet there is no question but that a sharp optical line of sight not only reduces this error greatly but eliminates the personal error of aligning the eye with two wires and a ground object. The actual average range error of $^1/_2$ deg., or 69 ft., from 8000 ft. altitude—comprising every error involved in sighting and release and indeterminate trajectory deviation, recently attained with a new sight employing an optical eyepiece—shows that the visual error in holding a ground object is very small indeed.

An error of $^1/_{32}$ in. may be assumed in the reading or resetting of scales, and any given instrument can be evaluated by the number of such observations necessary. Particular attention has been paid toward decreasing the number of operations involving possibilities of personal error, while improving instrumental accuracy.

Errors Independent of the Sight. Altimeters may be said to have been subject to roughly 5 per cent low indication in summer and 10 per cent high in winter.

EXAMPLE. Reading 6000, actual 6400. Time of fall $^2/_3$ sec. more than set for, being equivalent to 66 ft. at 100 ft. per sec. ground speed. Sight was set for 1930 ft.; actual angle subtends 130 ft. more, hence 130 − 66 = 64 ft. short in range. Thus an error of 6 per cent in altitude is not of much consequence above 5000 ft., but is increasingly serious at low altitudes.

Errors of air-speed indication have already been noted to involve comparatively small errors in the results with methods of ground-speed determination independent of wind and air speed. The Engineering Division is improving both altimeters and air-speed indicators.

In bombs of the same type, variation of trajectory from normal, due to manufacturing differences, is beyond control of the bomber or the instrument. The terminal velocity may vary slightly or the bombs wobble around the mean trajectory[1] due to fin deformities, slight out-of-balance, etc. This indeterminate dispersion is not much over 40 to 60 ft. from usual altitudes, and is very much less in bombs of the larger sizes and higher terminal velocities which are replacing the smaller types.

The normal gradation of air density with altitude is of course taken account of in bomb-trajectory data. The error due to variation from such normal gradation for a given stratum is negligible. The difference in trajectory for widely different strata would, however, be considerable, as for a drop from 5000 ft. to sea level compared to the same drop from 10,000 ft. to a target 5000 ft. above sea level. It is assumed that the bomber in setting any sight for altitude will subtract the target's altitude from the altimeter reading, but sights have not been provided heretofore with correction for different density strata, for the reason that bombing rarely involved very high objectives.

Change of wind during the bomb's drop is actually the source of very small range error due to a slight alteration of lag as an effective change in the bomb's air speed. The change of wind may be considerable as in a complete reversal of direction, though the average is small, but this change almost invariably occurs at low levels, and since the bomb covers the last third of its drop, say, 4000 ft., in $5^1/_2$ sec., or only one-fifth of the total time of fall, such change of the bomb's horizontal lag causes an inappreciable error.

Stabilization. Without stabilization it is obvious that a line of sight otherwise perfectly set for range and line will intersect the objective by an angular error of whatever angle off level flight the airplane may have at instant of intersection. It will be seen from the consideration of oscillations which follows, that errors from this cause were generally enormous when sights were merely fixed to the fuselage outside of the cockpit. Over and above periodic pitching and rolling, the heavy bomber may, in bumpy weather, roll, yaw, or pitch roughly 4 deg. from normal.

EXAMPLES. An inclination below horizontal flight of 4 deg. at instant of sight intersection means that the sight picks up the target too late, with about 590 ft. error in range.

Stabilization by damped pendulum has averaged better than $^1/_2$ deg., and with gyro stabilization (prorating errors from total actual results) better than 0 deg. 15 sec. has been attained, or less than 30 ft. ground error from 8000 ft. altitude.

The error due to the fact that the path of flight in a pitch or climb—and consequently the direction of the bomb—is 1 deg. from true horizontal at instant of release, is quite negligible as a ground-speed error compared to the error of intersecting the target 1 deg. too late or early.

Oscillations. Oscillations of the airplane, rolling, pitching, yawing, and bodily displacement and acceleration cause the line of sight to be thrown out of line or off the angle ahead of the vertical. If the whole airplane merely drops or rises in an air wave there is no tendency to displace the line of sight if the pendulum is in line with that acceleration. Acceleration not in line with the pendulum, such as change of horizontal speed or sidewise movement, produces error, but the rolling or pitching effect of such accelerations upon the sight are relatively unimportant if the pendulum is designed for the character of oscillations usually encountered.

Rolling and pitching are always present, even when the air is supposedly calm, in the form of periodic slow oscillations caused by the action of the restoring forces of the airplane's inherent stability. These oscillations are of the order of magnitude of from $^1/_2$ to $1^1/_2$ deg., with a period of about 20 sec., depending upon the type of airplane. In rough air, rolling and pitching of a bombing type will rarely exceed 5 deg. either side of normal. Rolling motion affects the accuracy of sighting to the greater extent in two ways. In observing the relative drift along the direction wire, an object seen at one instant beneath it will apparently move off to one side as if there were a real change in the direction of the earth drift, giving rise to an uncertainty—which may, however, be detected when followed by a similar motion in the opposite direction, as is usually the case if due to rolling.

The degree of directional accuracy depends upon the pilot's attention to his controls and close following of the indications from the bomber's observation of correct line. Steady piloting leads to a reduced rolling and is thus doubly essential to good bombing. It has been found that the rudder and aileron actually provide greater delicacy of control than the pilot can feel, and the inherent longitudinal and lateral stability of the airplane limits the extent of pitching and rolling more effectively than the pilot can within those limits, so that he had best leave the control of 1 deg. or less to the airplane with free controls rather than overcontrol by attempted correction.

Bubble levels, being subject to lag and errors of indications from accelerations, provide only approximate guides for holding the flight as steady as possible. Under airplane vibrations the bubble will frequently offset to such a degree that estimation would be as good.

The stabilization of the airplane itself, frequently proposed, is not only impractical in rough weather within the degree of stability required for sighting but is unnecessary so far as bombing goes, since stabilization of the instrument makes it independent of such oscillations within much closer limits than the airplane could be held.

METHODS OF OVERCOMING ERRORS AND THE RESULTS

The errors above cited in number and degree would leave the impression of greater bombing inaccuracy than actually obtained during the war. For, while the errors chosen for examples do fairly represent the wartime inaccuracies from the separate sources, they are not of course all cumulative, but some offset others, with the results of average radius of hit and percentage effectiveness as given below. Still, an error of 200 to 600 ft. from 6000 ft. altitude, while destructive against large objectives, would discount the certainty of battleship annhilation, except that postwar developments in the light of the following results attained reverse the conclusion.

Offset of the trajectory from a drift-ground course has been corrected for by aligning the ground course over a track parallel to the

[1] The bomb does not, as first supposed, travel tangent to the trajectory at all times, but oscillates with a period of about 1.6 sec. above and below this trajectory. This period of oscillation is nearly constant and varies as the square root of the moment of inertia of the bomb. The reason for this oscillation may be attributed to three forces acting on the bomb, namely, head resistance and resistance tangent to the trajectory, inertia, and gravity.

ground course through the objective but offset into the wind, by inclining the bomber's sight out of the vertical plane. This is done automatically through the movement of the sight off the fuselage center line, as a function of the drift angle, and the error is now practically nothing.

Alignment is no longer the source of the greatest error. This error has been reduced to an average of $1^1/_2$ deg., or 262 ft. from 10,000 ft. altitude, by providing the pilot with a director which is operated by angular difference between the bomber's sight to the target and his line on the ground travel; considerably less error is anticipated by combining a gyro or earth inductor compass to hold the pilot's line between the bomber's observations; but line error has already been reduced to 0 deg., 27 min., or 80 ft., from 10,000 ft. altitude in a recent test of an experimental system which gives the pilot instant indication of any lateral movement of the line of sight to the target. The effect of rolling on the pilot's indication is taken out by gyroscopic stabilization, and the system applies equally well in cross-wind or against moving targets. Error of alignment is now theoretically nothing, the above result representing the sum total of instrumental lag and small amounts of personal and stabilization errors remaining.

Correction of both line and range for target's speed at instant of bomb release has been completely taken care of. What naval vessels may do while the bomb is falling should receive more attention than it has heretofore, for the helplessness of the present type of larger ships to do anything in 35 sec. is deduced from naval statistics and is confirmed by high naval officials. Whether any type of ship can be designed to be reasonably safe in bombing from formations is a subject of much concern, and is an interesting problem from a viewpoint opposite to that of this presentation.

As to range errors, the trail of the trajectory is corrected in one instrument by setting for air speed and type of bomb, so that there is nothing left but the minute error from omitting, or only partly correcting for, time lag as an altitude factor, while in another instrument all three are corrected for with theoretical exactness.

Ground speed is measured by a timing method to within better than two miles per hour or three feet per second, and by a synchronous method to within about one mile per hour, equivalent to a range error of 39 ft. from 10,000 ft. altitude. This error is all that is left of combined personal error, instrumental lag, and error of stabilization.

Personal errors of operation and vision have been so completely eliminated by an automatic synchronous system that we scarcely know as yet how much of the half-degree error of the hit to apportion to them. The optical sight is manually held on an objective easily within 0.5 deg. even in rough weather, but this small amount is averaged out by a motor follow-up mechanism having a certain desirable degree of inertia, so that the only appreciable personal error remaining is in the setting of scales for altitude, air speed, and bomb type. These scales are so large and clearly defined that with reasonable care they can be set with no appreciable error at all. There is a possibility of making the altimeter and air-speed indicators set their own reading continuously and automatically, this being considered not because it can increase the accuracy, but to so completely relieve the bomber of thought that personal confusion and distraction cannot prevent success.

While altitude and air-speed indicators introduce relatively small errors, these are the sources of the largest errors now remaining and are worth more attention. Error of release delay is completely eliminated by automatic actuation by the bomb sight.

Stabilization is now very close to 0 deg. 10 min. by gyroscop and relay motor control, equivalent to 30 ft. at 10,000 ft. altitude. We would not venture to predict much better than this, improvement lying perhaps in the design of precession correction for the insurance of its accuracy under all kinds of oscillations.

The results come down to a summation of personal and instrumental errors, which is so small that the next step appears to be the refinement of the details of the apparatus to insure infallible functioning rather than the effecting of any further accuracy, for it will be noted that the astonishing results given in Fig. 8 are almost within the variation of the bomb's trajectory itself from causes of indeterminate amounts such as wobbling or the wind variation during the drop, which cannot practically be determined for correction.

The time required to line and set the instrument is a handicap to successful bombing in proportion to the exposure to anti-aircraft measurements during straight flight necessary just previous to release.

Wartime sights averaged from 40 sec. to 2 min.; limited to approach up or down wind and against fixed targets only; they were practically limited in effectiveness to considerably under 10,000 ft. and thus gave comparatively poor results when forced by anti-aircraft in day bombing to 12,000 to 15,000 ft. Fifteen thousand feet was considered "safe," 12,000 ft. was "reasonably safe," and much was done below where it was not even reasonable; nevertheless the pilot's chance was better than 1500 to one. The menace of anti-aircraft from 10,000 to 20,000 ft. is a conjecture which is decidedly doubtful in the light of recent events. But allowing the most accurate sighting attainable, anti-aircraft cannot prevent bombing under weather conditions favoring the bomber about one-third of the time.

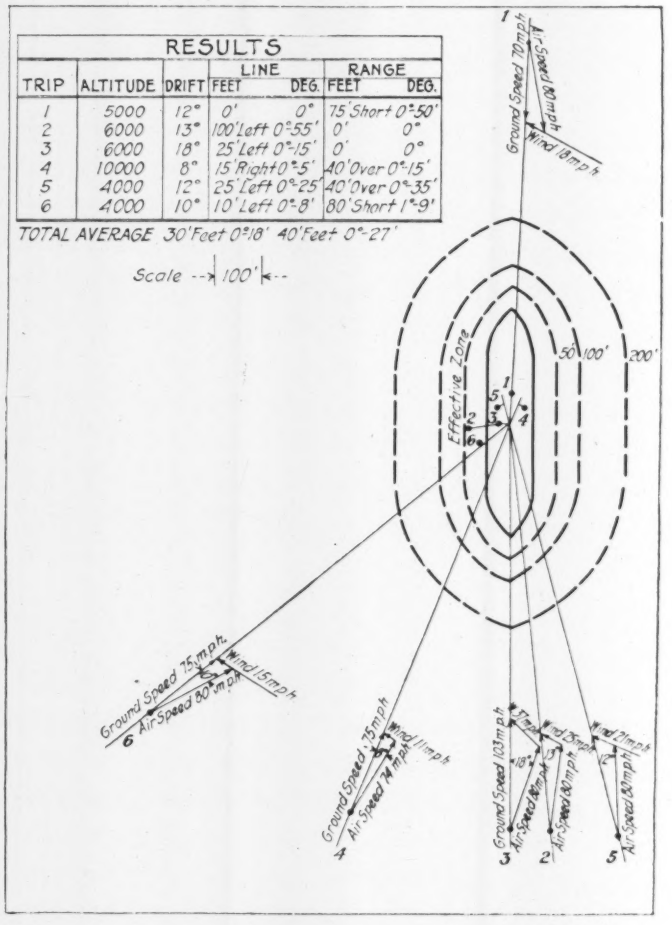

RESULTS
TRIP | ALTITUDE | DRIFT | LINE FEET | LINE DEG. | RANGE FEET | RANGE DEG.
1 | 5000 | 12° | 0' | 0° | 75' Short | 0°-50'
2 | 6000 | 13° | 100' Left | 0°-55' | 0' | 0°
3 | 6000 | 18° | 25' Left | 0°-15' | 0' | 0°
4 | 10000 | 8° | 15' Right | 0°-5' | 40' Over | 0°-15'
5 | 4000 | 12° | 25' Left | 0°-25' | 40' Over | 0°-35'
6 | 4000 | 10° | 10' Left | 0°-8' | 80' Short | 1°-9'
TOTAL AVERAGE 30' Feet 0°-18' 40' Feet 0°-27'
Scale --> 100' <--
Effective Zone
50' 100' 200'
Ground Speed 70 m.p.h.
Air Speed 80 m.p.h.
Wind 18 m.p.h.
Ground Speed 75 m.p.h.
Air Speed 80 m.p.h.
Wind 15 m.p.h.
Ground Speed 75 m.p.h.
Air Speed 74 m.p.h.
Wind 11 m.p.h.
Ground Speed 103 m.p.h.
Air Speed 80 m.p.h.
Wind 37 m.p.h.
Air Speed 80 m.p.h.
Wind 37 m.p.h.
Air Speed 80 m.p.h.
Wind 11 m.p.h.

FIG. 8 RESULTS OF BOMBING TESTS

NOTE: Approaches were made in random directions without regard to velocity or direction of wind. Drift angles were approximately as shown, but alignment of the ground coarse is automatic whatever the wind velocity, direction, or drift angle, and whether the objective is fixed or moving.

Recent devices have cut the time of straight flight down to from 7 sec. to 22 sec.; they are not limited as to direction of approach and are applicable to fixed or moving targets; they are provided for 22,000 ft. altitude, where the accuracy is equivalent to that heretofore attained at less than 7000 ft. Wartime sights (averaging three types in general use and 159 records, representing mixed conditions) gave an error of 490 ft. radius, or roughly a 5-deg. error, lumping all altitudes actually used, averaging 6000 ft. These sights gave 83 per cent effective hits on large land objectives, as 350 yd. by 500 yd.; 66 per cent effective hits on small land objectives, as 150 yd. by 200 yd.; and 20 per cent effective hits on battleships.

One instrument developed by the Engineering Division of the Air Service and utilizing a timing method has given an average of 120 ft. radial error from 6000 ft. altitude, while another experimental development employing a synchronous system averaged 40 ft. radius from the same average altitude.

The Value of Efficiency in Transforming and Distributing Energy

By CHARLES E. LUCKE,[1] NEW YORK, N. Y.

AT THE PRESENT TIME it would be hard to find a problem of greater public importance confronting the engineer than that of better supplies of heat and power, nor one in which there is such general recognition by all classes of people that the engineer is the man who must assume the responsibility for its solution. It requires no statistics to prove the growth of power uses and the benefits to be derived by the country as a whole through further extension of the use of power, though statistics are available in abundance for both stationary and transportation applications of power. Heat supplies always have been recognized as a public necessity for comfortable living in our climate, and while the increase in the use of heat for domestic purposes has grown but little in proportion to population as compared with power, there has been a material increase for industrial processes independent of such fuel as is required for power generation. There has, however, been a very considerable rise in the cost of heat without a corresponding rise in the cost of power. That power supplies have been made available at but little rise in cost in proportion to the increase in cost of fuel, its main energy source, is in itself an engineering achievement not as fully recognized as it should be, and one that justifies the expectation that further engineering effort in this direction will produce results of such magnitude and public value that they will meet the requirements of public welfare, and will bring with them that recognition of engineering which will justify further confidence and responsibilities.

Importance of Energy Costs

There is a real necessity for discovering ways to reduce the cost of power at the point of use as a means of increasing the extent of use, and an equal desirability if not necessity for corresponding reductions in the cost of heat. Cheaper heat and cheaper power are very closely related national problems, but the discovery of best solutions is an engineering problem, one to be solved only by engineering methods. Engineers know these things and each of many thousands of them is engaged on some one phase of the problem which is of direct interest to himself or his employer, but there seems to be a lack of complete coördination of these efforts, with evidence of working at cross-purposes or destructive competition of effort that might well be reduced in the interests of real, substantial progress. A survey of all of these activities will reveal a situation of exceeding complexity and one so confusing as to justify any effort to clarify it, even partially.

Part of the difficulty is due to the discoveries of new scientific facts and principles, including rational invention. This is healthy and must be encouraged, but as in all lines of activity, direction is necessary if a given amount of effort is to produce most useful results. Many a good man has wasted his life solving problems that were not worth solving, exhibiting genius which, if it had been guided in other directions, might have made him a public benefactor. Another cause of confusion and conflict of effort is due to the active commercial competition of the interests of the engineer's employer. This also is inevitable and normally a good thing. It may be even an economic necessity, but often it is not. Sometimes it is entirely wrong and unjustifiable, but frequently it is based on wrong advice from the engineer who is "riding a hobby," or who has not kept up with professional progress and has too narrow a viewpoint. Whole groups of both employing interests and their engineers may be found working in opposition, each seeing only their own immediate problems and perhaps unconscious of conflict with the other group, or if conscious, unable to see any community of interest justifying a program of coöperation instead of opposition or competition. Finally there must be noted real changes in economic conditions which not only justify but require a change in ideals or methods, making that which was right yesterday entirely wrong today and with the prospect of still other changes tomorrow. Most of these changes can be predicted by study soon enough to avoid serious errors, but sometimes, as in the case of the late war, this is impossible.

What is right will prevail in the end in spite of any effort in the counter direction by forces however powerful, but waiting for time to correct errors is not the engineering method and is terribly costly. It is the duty of engineers to at least try to find a sound basis for a procedure and to act on convictions of right derived from an analysis of all available facts, principles, and even probabilities, some of them deep and some of them broad, not confusing depth with breadth, nor yielding to one in favor of the other. Periodic surveys are most helpful, in fact they may be regarded as real necessities in any effort to discover the trend of affairs, the direction in which effort is likely to be most fruitful, and the place where deep analysis or development is justified by prospects of return.

The very complexity of the problems connected with the most effective distribution of heat and power service at least cost, at this time of so many revolutionary ideas and of conflict of opinion, requires a series of survey studies of great breadth very much more than it does increased intensity of effort at any one point. Any such survey must start with the understanding that fundamentally the complexity and confusion are due to the fact that there are many ways of doing each thing to be done, all of which alternatives are in competition with each other, and that there is no adequate measure by which to judge values so as to clearly lead to a decision as to which alternative is best or which of more than one are equal in merit.

Assuming that one may list all the alternative ways of accomplishing a given object—systems, plants, units, or methods—then the search for a solution of the problem of distinguishing the best from the worst and grading the others between becomes one of adequacy of the measure to be applied. Such a measure or basis of judging competition must be simple and easy to apply if it is to be useful, and it must be complete and conclusive to be acceptable.

In setting up such measures of competitive value there are two steps necessary, or rather there are two typical but wholly different sorts of measure. The first is "suitability," the other is "cost." Two alternatives may not be equally suitable, and if the difference is large the more unsuitable one must be rejected regardless of cost. The steam turbine for locomotives as compared with locomotives employing pistons in cylinders is an example of this, and the driving of high-head centrifugal pumps by direct-connected oil engines without gears is another.

However, when there are two alternatives each equally suitable for a given purpose, the choice must rest on costs. That one which produces the result at least cost is the better, so that the cost of the service prevails when the suitabilities are equal. This is the case when in a steam plant one boiler-room equipment is to be compared with another, or oil engines, steam turbines, or hydraulic turbines are to drive electric generators. There is, however, a third case, and it is the most difficult of all. This is where suitability and costs are both unequal, and when the lesser suitability corresponds with lesser costs.

Considering first the general situation as to competition or alternatives in means of supplying heat and power, it is worth while to enumerate a few things for the sake of completing the picture, even if they are not new.

What is there common to the problem of mining and distributing coal in railroad cars, boats, and trucks as a primary source of

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[1] Professor of Mechanical Engineering, Columbia University. Mem. A.S.M.E.

Presented at a meeting of the Metropolitan Section of The American Society of Mechanical Engineers, New York, April 22, 1924; before the Schenectady Branch of the Eastern New York Section on April 25; and before the Boston Section on May 6.

energy for heating or for power generation, and to that of the electric utilities as producers and distributers of electrical energy? The production of oil and natural gas and their distribution by means of pipe line, tank ship, railroad car or truck as the other primary source of energy for heat or power generation, would seem to be in competition with coal production and distribution. But are they? There are some clearly defined differences, and analysis may show that there are, or will be, more. The gasoline automobile as a utilizer of gasoline—one petroleum product—is, in this country, not in competition with coal-utilizing equivalents, and yet fuel oil, another petroleum product, is not in the same position competitively with reference to coal for utilization in steam-boiler or other furnaces. Is the oil engine utilizing fuel oil for generating power in competition with coal-burning steam equipment, or is it not? Is it competitive in some cases and not in others? Are there any cases in which one is definitely superior to the other? Is the answer the same for railroad, automobile, ship, and stationary purposes? Is the railroad car as a transmitter of energy in competition with the oil pipe line or the gas pipe line carrying gasified coal, or is it not? Is the answer the same if the fuel is to be utilized for heating or for electric power generation, and if the latter, is the transportation system of the fuel in competition with the electric transmission lines for part or all of the distance between the mine or well and the consumer of electricity? In the latter case, to what extent is hydroelectric transmission in competition? In any electric distribution system from central stations, to what extent is local generation at the point of use in competition with transmitted electricity, and by what system?

In the transportation field there are special problems of a similar nature, one vehicle of transportation in competition with another—rail, water, overland, and air—with different answers according to route, size of vehicle, and traffic density. There is, in addition, corresponding competition between systems of powering each vehicle—gasoline engine, oil engine, steam plant, and electric trolley or storage battery with central-station connections. In the case of steam locomotives there are further varieties of detail besides design factors—the use, extent of use, or non-use of superheaters, feedwater heaters, economizers, stokers; and in the case of internal-combustion engines, first, the type of gasoline or the several varieties of oil engine, and second, the control and transmission to the wheels by gears—hydraulic, compressed air or electric—with many varieties and combinations of each. All this is repeated for ships and automobiles.

In the stationary steam field, in addition to the old competition between the reciprocating engine and the steam turbine, the superiority of the latter now being acknowledged as regards large sizes, there has now appeared as new competition the use of high-pressure steam—in excess of 1000 lb. per sq. in., with all intermediate ranges down to old values—superheat temperatures up to metal-oxidizing or softening values, with reheating between stages, stage bleeding to heat feedwater with electric auxiliaries, steel-tube economizers, water degasifiers, boiler-air preheating, automatic control of ratio of boiler air to fuel weights, and innumerable other changes of details of units and combinations, not to mention the revival of the old binary system by introducing mercury vapor in series with steam instead of other vapors.

Having selected any one of these sets of alternatives, there must next be established a cost basis by which to judge between two or more that are equally suitable—and which therefore are really competitive from the suitability standpoint—or where costs must be considered, with unequal suitability to reach a decision. It usually happens that suitability is easily judged and is often quite obvious.

There is, however, never anything obvious about relative costs of results by alternative or competitive means, especially, as is usually the case, when one cost factor is least for one alternative and another least for some different alternative. One of the commonest cases of this sort is that in which the process involves an energy loss and for which, therefore, the efficiency is less than 100 per cent for all alternatives, but where the investment costs are inversely related to efficiencies, with operating costs miscellaneously distributed. This complex case is especially aggravated, assuming power generation to be the problem, when the cost of the primary or source energy available for each system is not the same at the point of generation, and still worse when primary energy costs available for each alternative also vary relatively at different points on an electrical distribution system, any point of which might be a local generating point instead of a substation or consumer point.

Any cost system that can give a correct picture of competitive values for both heat and power, and when applied either to a power or heat problem will exhibit clearly the relative influence on increasing costs at successive points, of efficiency between points, and of the investment for equipment with disbursement incident to its use, must be based on one common unit for all. The best unit is the British thermal unit, and for it the common identical conversion factors are: 2545 B.t.u. = 1 hp-hr., and 3415 B.t.u. = 1 kw-hr.

The first step in the cost system necessary for judging all sorts of competition in heat and power problems is the setting up of all costs in terms of cost of energy at any point and in any form, and it is most convenient to use costs in terms of cents per million B.t.u. As a convenience in the conversion of electric power costs, commonly expressed in cents per kilowatt-hour, the figures of Table 1 have been worked out showing cents per million B.t.u.

TABLE 1 CONVERSION EQUIVALENTS—CENTS PER KW-HR. TO CENTS PER MILLION B.T.U.

Cents per kw-hr.	Cents per 1,000,000 B.t.u.	Cents per kw-hr.	Cents per 1,000,000 B.t.u.	Cents per kw-hr.	Cents per 1,000,000 B.t.u.
0.1	29.282576	3.6	1054.172736	7.1	2079.062896
0.2	58.565152	3.7	1083.455312	7.2	2108.345472
0.3	87.847728	3.8	1112.737888	7.3	2137.628048
0.4	117.130304	3.9	1142.020464	7.4	2166.910624
0.5	146.412880	4.0	1171.303040	7.5	2196.193200
0.6	175.695456	4.1	1200.585616	7.6	2225.475776
0.7	204.978032	4.2	1229.868192	7.7	2254.758352
0.8	234.260608	4.3	1259.150768	7.8	2284.040928
0.9	263.543184	4.4	1288.433344	7.9	2313.323504
1.0	292.825760	4.5	1317.715920	8.0	2342.606080
1.1	322.108336	4.6	1346.998496	8.1	2371.888656
1.2	351.390912	4.7	1376.281072	8.2	2401.171232
1.3	380.673488	4.8	1405.563648	8.3	2430.453808
1.4	409.956064	4.9	1434.846224	8.4	2459.736384
1.5	439.238640	5.0	1464.128800	8.5	2489.018960
1.6	468.521216	5.1	1493.411376	8.6	2518.301536
1.7	497.803792	5.2	1522.693952	8.7	2547.584112
1.8	527.086368	5.3	1551.976528	8.8	2576.866688
1.9	556.368944	5.4	1581.259104	8.9	2606.149264
2.0	585.651520	5.5	1610.541680	9.0	2635.431840
2.1	614.934896	5.6	1639.824256	9.1	2664.714416
2.2	644.216672	5.7	1669.106832	9.2	2693.996992
2.3	673.499248	5.8	1698.389408	9.3	2723.279568
2.4	702.781824	5.9	1727.671984	9.4	2752.562144
2.5	732.064400	6.0	1756.954560	9.5	2781.844720
2.6	761.346976	6.1	1786.237136	9.6	2811.127296
2.7	790.629552	6.2	1815.519712	9.7	2840.409872
2.8	819.912128	6.3	1844.802288	9.8	2869.692448
2.9	849.194704	6.4	1874.084864	9.9	2898.975024
3.0	878.477280	6.5	1903.367440	10.0	2928.2576
3.1	907.759856	6.6	1932.650016		
3.2	937.042432	6.7	1961.932592		
3.3	966.325008	6.8	1991.215168		
3.4	995.607584	6.9	2020.497744		
3.5	1024.890160	7.0	2049.780320		

equivalent to cents per kw-hr. from 0.1 cent to 10 cents per kw-hr., from which other values can be determined by shifting decimal points and by addition.

Considered in its broadest possible aspect, the national problem of heat and power supplies is that of discovering the cheapest way of bringing primary energy from its source to the point of use in acceptably suitable form. There are three such forms:

a Heat, to be utilized as heat

b Electricity, to be utilized as electricity

c Power, in the form of motion against resistance.

The common sources of primary energy are fuels: coal, oil, and gas in the earth, and water at an elevation. To get a correct picture of the whole process the energy costs in cents per million B.t.u. must be evaluated and periodically checked from source to point of consumption, and at every point between where there is transportation, transmission, or transformation. The more completely this is done, the more clearly it will appear just where costs have accumulated most and where, as a consequence, it is most worth while to exert effort to reduce costs. It will also appear that in this train of successive cost accumulations, other things being equal, the earlier in the train a saving is effected, the greater the ultimate effect at the end of the train, especially when the cost accumulation is the result of inefficiency or actual energy losses rather than high investments or operating disbursements. Exactly the same system and with the same units, when brought down to individual stages of a process, will clearly show the value of efficiency or energy losses, investments, and operating disbursements to control the losses in effecting either transformation of energy from one form to another or its transmission in any one form.

It is a principle generally applicable to every such process step that a cost at any one point in the train of transmission and transformation from mine, well, or waterfall to the point of consumption is the cost of all the operations plus the original cost of energy at the starting point.

Each operation or process step adds three cost increments, namely,

a An increment due to loss of energy
b An increment due to equipment investment, and
c An increment due to operating disbursements.

For a single operation starting at point A and ending at point B, the costs are formulated as follows:

Cost in cents per million B.t.u. at B (B) = Cost at A (A), plus inefficiency increment (xA), plus investment increment (I), plus operating disbursement increment (O), or

$$B = A + xA + I + O$$

If E = efficiency from A to B = ratio of output to input energy, then

$$A + xA = \frac{A}{E} \quad \text{and} \quad x = \frac{1 - E}{E}$$

Therefore the inefficiency increment of cost is $(1 - E)A/E$ and the total cost increments for the process are

$$B - A = \left(\frac{1 - E}{E}\right) A + I + O$$

This leads to two expressions for the cost per million B.t.u. at the end in terms of cost at the beginning, the efficiency of the process, and the expenses for investment and operation. These are:

$$B = \frac{A}{E} + I + O$$

$$= A + \left(\frac{I - E}{E}\right) A + I + O$$

With this formulation it now becomes possible to establish a measure of *commercial efficiency*, E_c, for the process with an algebraic relation to its energy efficiency E. Defining commercial efficiency as the ratio of cost of input energy to cost of output energy, each in cents per million B.t.u., then,

$$E_c = \frac{A}{\frac{A}{E} + I + O}$$

$$= \frac{AE}{A + E(I + O)}$$

$$= \frac{E}{1 + E\left(\frac{I + O}{A}\right)}$$

Interpreting this expression, the commercial efficiency is equal to the process efficiency, divided by 1 plus the product of process efficiency and the ratio of process expenses to original cost. As the denominator is always greater than unity, the commercial efficiency will always be less than the process efficiency.

A numerical example will make these relations more clear. Assume energy of fuel costing 32 cents per million B.t.u. to be transferred to energy of steam available for a turbine with an overall process efficiency of 60 per cent, and requiring an investment that adds 30 cents per million B.t.u. output, with operating disbursement adding 25 cents more.

Then the inefficiency increment of cost will be

$$\left(\frac{1 - E}{E}\right) A = \left(\frac{1.0 - 0.6}{0.6}\right) \times 32 = 21.33 \text{ cents}$$

$$B = A + \left(\frac{1 - E}{E}\right) A + I + O = 32 + 21.33 + 30 + 25 = 108.33$$

or $$B = \frac{A}{E} + I + O = \frac{32}{0.6} + 30 + 25 = 53.33 + 30 + 25 = 108.33$$

and

$$E_c = \frac{A}{B} = \frac{32}{108.33} = 29.5 \text{ per cent}$$

$$= \frac{E}{1 + E\left(\frac{I + O}{A}\right)} = \frac{0.6}{1 + 0.6\left(\frac{55}{32}\right)} = 29.5 \text{ per cent}$$

For this case an energy efficiency of 60 per cent yields a commercial efficiency of only 29½ per cent.

This method of judging processes is applicable to a series of processes constituting a system of transforming or of transmitting energy in any form. It is of special value in appraising alternatives for single processes or systems where efficiencies of processes or systems may vary considerably with equipment investment and operating disbursement expenses. It shows directly the value of efficiency in terms of all prime variables through the approach to equality of commercial efficiency and process efficiency. That process efficiency or system efficiency is most valuable whose commercial efficiency is most nearly equal to its own value, and of course when both are as high as possible.

In what follows are collected some estimates of costs for primary energy and for its power-plant transformation into electrical energy through appropriate steps, to illustrate the use of the method. These estimates are reasonably close to fair or representative values, though they may not exactly check with some individual cost sheet. They lead to certain conclusions that are sufficiently interesting to justify a most complete analysis of every phase of the power- and heat-supply situation by engineers and corporations interested in each part of it and having available most complete data on efficiencies and costs applying to the case.

Primary Energy at the Source

Starting with primary energy, it may be said that water in a stream or coal, oil, and gas in the earth are worth nothing as they are. Whatever value may be fixed by appraisal must be based on costs of subsequent operations required to bring them in one form or another to the consumer—with due regard to competitive demand.

Coal brought to the surface by mining operations has a value shown by daily quotations and this value is more or less closely related to the mine operating cost; and while these prices and costs are subjects for investigation by mine owners, mining engineers, and economists treating coal as a commodity, they must be accepted by engineers concerned with coal as energy and with energy distribution as a service rather than a commodity. For present purposes costs of energy in the form of coal f.o.b. mines are taken at random from *The American Metal Market and Daily Iron and Steel Report* and set down in Table 2.

TABLE 2 COAL COSTS AT MINES IN DOLLARS PER TON AND CENTS PER MILLION B.T.U. (RUN-OF-MINE COAL)

		High		Low	
Field	B.t.u. per lb.	Dollars per ton	Cents per million B.t.u.	Dollars per ton	Cents per million B.t.u.
Northern Illinois	10,981	2.75	12.52	2.25	10.24
	12,488	2.75	11.01	2.25	9.01
Central Illinois	10,514	2.25	10.70	2.00	9.51
Southern Illinois	10,981	2.75	12.52	2.50	11.38
	12,276	2.75	11.20	2.50	10.18
Indiana Fifth Vein	12,409	2.25	9.07	2.00	8.06
	11,192	2.25	10.05	2.00	8.93
Western Kentucky	11,900	2.25	9.45	1.50	6.30
	12,500	2.25	9.00	1.50	6.00
Ohio No. 6	12,560	2.05	8.16	1.95	7.76
Eastern Ohio	12,560	2.00	7.96	1.90	7.56
	12,100	2.00	8.26	1.90	7.85
Pittsburgh	13,900	2.10	7.55	1.90	6.83
Central Pennsylvania	13,600	1.75	6.43	1.60	5.88
	14,500	1.75	6.03	1.60	5.52
Connellsville (steam)	13,990	1.50	5.36	1.35	4.82
West Virginia	12,265	1.60	6.52	1.35	5.50
	15,200	1.60	5.26	1.35	4.44
West Virginia, Pocahontas	13,995	2.25	8.04	1.50	5.36
Do., New River	15,208	2.25	7.40	1.50	4.93
Do., Panhandle	14,250	1.95	6.84	1.90	6.67

Reference to this table shows that energy in the form of coal at the mines costs from 4.44 (minimum) to 12.52 (maximum) cents per million B.t.u.

Oil brought to the surface at a well has a value practically not at all related to the cost of sinking and operating the particular well, being affected by a great many hazardous factors incident to the oil-production business. Due to the necessity for refining operations to develop maximum value, prices for nearly all crudes at refinery are more indicative and comparable with coal at mines. The figures given in Table 3 are from quotations appearing in the

TABLE 3 PETROLEUM FUELS—COSTS AT REFINERY, F.O.B. TANK CAR

Fuel	Gravity, deg. Baumé	Lb. per gal.	B.t.u. per lb.	Destination	High: Cents per gal.	High: Cents per million B.t.u.	Low: Cents per gal.	Low: Cents per million B.t.u.
Fuel Oil	36–40	6.939	19,770	Pennsylvania	6¼	45.5	6	43.6
	30–34	7.196	19,530	Pennsylvania	5½	39.2	5¼	37.4
	38–40	6.898	19,810	Oklahoma	4⅛	30.0	3⅞	29.0
	32–36	7.108	19,610	Oklahoma	3⅝	26.0	3⅜	24.2
	24–26	7.522	19,250	Oklahoma	2¾	19.0	2⅝	18.2
	38–40	6.898	19,810	N. Texas	4½	33.0	4¼	31.2
	32–36	7.108	19,610	N. Texas	3¾	27.0	3½	25.2
	24–26	7.522	19,250	N. Texas	3¼	22.4	3	20.7
Kerosene	45	6.661	19,840	Pennsylvania	8	60.5	7¾	58.5
	47	6.586	19,520	Pennsylvania	9¼	73.3	...	...
	40–42	6.817	19,680	Oklahoma	5¼	39.1	5	37.2
	42–44	6.738	19,760	Oklahoma	6	45.1	5¾	43.2
	40–42	6.817	19,680	N. Texas	5½	40.8	5	37.2
	41–43	6.777	19,720	N. Texas	6	44.8	5¾	42.9
Gasoline	58 straight	6.199	20,240	Pennsylvania	15½	124.0	15	120.0
	68 straight	5.886	20,640	Pennsylvania	20	164.0	19½	160.0
	60–70 blend	5.976	20,520	Pennsylvania	16	130.0	14¼	116.0
	56–58 blend	6.233	20,200	Oklahoma	11	87.5	10¾	85.5
	68–70 blend	5.856	20,680	Oklahoma	14	116.0	13¾	114.0
	52–58 blend	6.334	20,160	N. Texas	11	86.0	10½	82.0
	68–70 blend	5.856	20,680	N. Texas	14¼	117.0	14	115.0

National Petroleum News for fuel oil, kerosene, and gasoline, the normal fuel products of crude. Of these figures those most directly comparable as to use with coal are the values for fuel oil which range from 18 (minimum) to 45 (maximum) cents per million B.t.u. approximately, and which are respectively 3½ and 3¾ times the corresponding minimum and maximum coal values.

Considering the fact that electrical energy generated from fuel is sold at retail to small consumers at prices ranging around 10 cents per kw-hr., and at wholesale to large ones at 2 cents, there is evidently a very large cost accumulation in the whole series of processes of transportation and transformation from point of production to consumer. As 10 cents per kw-hr. is equivalent to 2898 cents per million B.t.u., the small consumer pays from 200 to 500 times as much for energy in the form of electricity at the point of consumption as it cost in the form of coal at coal-production points, and the larger consumer about one-fifth as much, or 40 to 100 times the original value. The difference between the wholesale and the retail price is a measure of the great cost of retail business, the largest single cost accumulation of the system.

Even these wholesale cost accumulations are large, corresponding as they do to about 1 per cent and 2½ per cent commercial efficiency, and they focus attention on the analysis of all the separate items of accumulation as a necessary first step in any orderly survey of means of improvement.

The Transportation or Transmission of Primary Energy

The first cost accumulation is that resulting from the transportation of the fuel in its original form—and this is a matter of freight rates—by truck, railroad car, and boat for both coal and oil, with the special case of the pipe line for oil as an alternative. Freight rates by railroad show some very remarkable things. For practically all fuels the cost accumulation by rail transportation exceeds the cost at the mines and in many cases the original cost is multiplied several times. This is especially serious when it is realized that this is the first operation in the series of processes from source of energy to consumer and that early multiplications are themselves later multiplied in succession in a sort of geometrical progression. Furthermore, freight costs will show no relation between actual cost of transportation or distance. A few figures from recent coal quotations will show the magnitude of the charges.

The freight charge on coal from the New River Pocahontas field to New York is $3 per ton for 614 miles or 0.49 cent per ton-mile, and to Boston, 846 miles, $3.25 or 0.385 cent per ton-mile. Pennsylvania coal to New England costs $4, and taking 600 miles as the distance the rate is 0.67 cent per ton-mile as a mean for a considerable range of distance. From Central Illinois to Chicago the rate is $1.85, which is just about 1 cent per ton-mile. These figures show a range of from 0.3 to 1.0 cent per ton-mile, quite independent of such special cases of rates where short hauls cost more than long ones.

The transportation of oil in pipe lines costs less than it does in tank cars and it is probably the cheapest system of energy transmission known, but the economies are only partly reflected in the rates allowed to pipe lines as common carriers. The following figures for crude from Pogue show in all cases a differential in favor of the pipe line and are of interest relatively. From the Cushing field to Kansas, 117 miles, the rates (in 1916) were 0.311 and 0.200 cent per bbl. by rail and pipe line, respectively; to Illinois, 565 miles, 0.544 and 0.340 cent, to Port Arthur, 583 miles, 0.466 and 0.400 cent; to Indiana, 686 miles, 0.622 and 0.420 cent. These figures are equivalent to 1.87, 0.67, 0.56 and 0.63 cents per ton-mile by rail for 117, 565, 583 and 686 miles, respectively, which are higher than the coal rates. By pipe line the ton-mile rates are 1.2, 0.42, 0.48 and 0.43 cents, which are respectively 64, 63, 85 and 68 per cent of the rail rates.

On the B.t.u. basis, using the above figures for coal (0.3 to 1.0 cent per long ton per mile) and taking a ton as 30 million B.t.u., in round numbers the costs are 1.0 cent to 3.3 cents per million B.t.u. per 100 miles or per hundred million B.t.u.-miles.

In the Superpower Survey report of U. S. Geological Survey, Professional Paper No. 123, 1921, still higher figures are given for the transportation of coal in the superpower zone as shown in Table 4; these, however include taxes, insurance, and seasonal storage cost.

These figures result from the application of the rate-making principles of the Interstate Commerce Commission which are based

TABLE 4 COAL TRANSPORTATION COSTS
(Superpower Report Estimates, 1925–1930)

Consumption Point	Transportation Cost in Dollars per Ton of 2000 lb. from Clearfield	Fairmont	Pocahontas
Boston	4.45	4.68	5.40
Providence	4.59	4.81	5.15
New London	3.93	4.16	5.40
New Haven	3.81	4.18	...
Hartford	4.33	4.55	...
Northampton	4.83	5.07	...
Albany and Poughkeepsie	3.43	3.80	...
New York, Newark, and New Brunswick	3.35	3.66	...
Trenton	3.17	3.40	...
Harrisburg	2.53	2.77	...
Philadelphia, Washington, Baltimore and Wilmington	3.05	3.27	...

on economic theories of commodity distribution and railroad support, and are quite as independent of actual costs as is the price of crude oil to its production cost in any given case. It is of the greatest possible importance that efforts be made to reduce this cost of transportation of primary energy in the form of fuel for all subsequent operations leading up to final use as heat, power, or electricity, but no progress can be made without a change of ideas and of methods. The first step is to change the idea of fuel as a commodity to that of energy, and the second step is an investigation of every possible alternative mode of transmitting energy in forms available for both heat and power, even new ways, with the hope that the cheapest discovered may be adopted for any given locality without the interference of irrational rate handicaps that might be justified for commodities like wheat. There should be some consistent relation between energy-distribution rates in various forms—electricity over wires, gas and oil in pipes, or coal or oil by rail—and cost should be a factor to justify efforts to discover economies by allowing rewards to be collected for the successful effort.

Primary-Fuel Energy Cost at the Point of Use

As has been pointed out, coal from different mines delivered to different points suffers cost increments over the cost at mine that are always considerable—normally several times the mine cost—and that are, moreover, not proportional to distance. The effect is to more or less equalize the cost of coal energy at points of use at different distances from the mine by adding a considerable amount to the mine costs, but in general adding proportionately more to short than to long distances. When two or more such fuels from different sources are available in the same market and are of different heating value, the tendency is to make them com-

petitive by adjustment of price, so that the cost per million B.t.u. will be highest for the fuels most easily utilizable.

This same tendency exists with regard to petroleum products

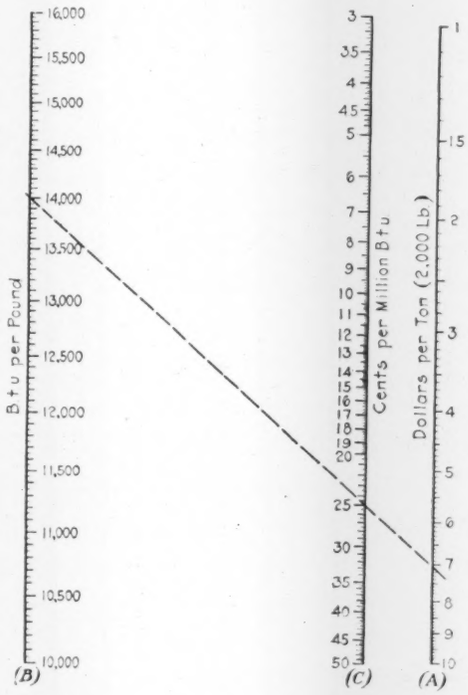

FIG. 1 COST OF ENERGY OF SOLID FUEL IN CENTS PER MILLION B.T.U.

$$\text{Cents per million B.t.u.} = \frac{\text{Dollars per ton} \times 100 \times 1{,}000{,}000}{\text{B.t.u. per lb.} \times 2{,}000} = (C) = \frac{(A)}{(B)}$$

EXAMPLE: Dollars per ton = 7; B.t.u. per lb. = 14,000

$$\therefore \text{Cents per million B.t.u.} = \frac{7 \times 100 \times 1{,}000{,}000}{14{,}000 \times 2{,}000} = 25$$

By Chart: (A) = 7; (B) = 14,000; ∴ (C) = (A)/(B) = 25 (check)

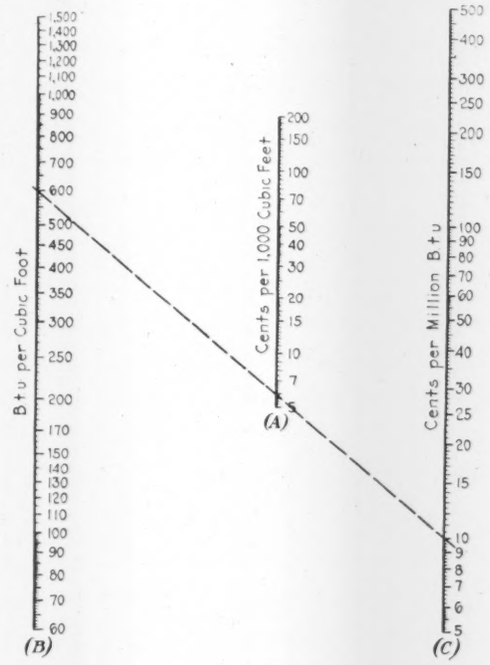

FIG. 2 COST OF ENERGY OF GASEOUS FUEL IN CENTS PER MILLION B.T.U.

$$\text{Cents per million B.t.u.} = \frac{\text{Cents per 1,000 cu. ft.} \times 1{,}000{,}000}{\text{B.t.u. per cu. ft.} \times 1{,}000} = (C) = \frac{(A)}{(B)}$$

EXAMPLE: Cents per 1000 cu. ft. = 6; B.t.u. per cu. ft. = 600

$$\text{Cents per million B.t.u.} = \frac{6 \times 1{,}000{,}000}{600 \times 1000} = 10$$

By Chart: (A) = 6; (B) = 600; (C) = (A)/(B) = 10 (check)

of different use values competing one with another—fuel oil, gas oil, kerosene, or gasoline—and also with regard to fuel oil, the less useful of this series, competing with coal. On this basis, fuel oil selling at the same cost per million B.t.u. as coal would drive coal out of use. Wherever both are used the price ratio of oil to coal will be greater than 1.0 and may rise to 2.00 or more, the higher values permitting oil to be used in proportion as utilization costs favor the oil.

Some comparatively recent quotations on coal in various cities are given in Table 5, together with fuel-oil values, from which the price ratios are seen to vary from 1.25 to 3.78.

These coal prices may be compared with those given in the Superpower Report as estimated for 1925–1930, taking Clearfield as indicative for bituminous coals for this district, which ranges from a minimum of $5.43 per ton at Harrisburg to $7.73 per ton at Northampton, with intermediate rates of $6.25 at New York and $7.35 at Boston.

For retail consumption, prices are very much higher—two to three times. For a good part of the eastern district large sizes of anthracite cost $15 per ton, more or less, and buckwheat No. 1 $10 and No. 3 $7.50, which latter is to be compared with mine costs

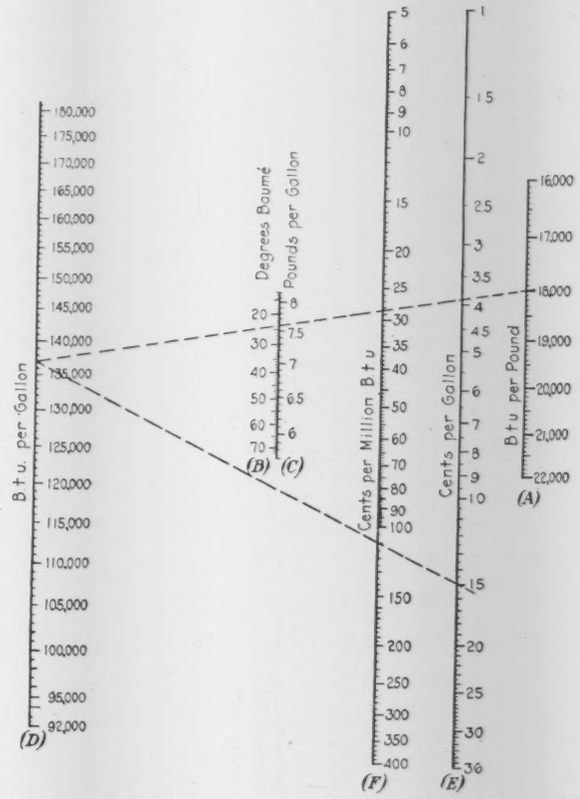

FIG. 3 COST OF ENERGY OF LIQUID FUEL IN CENTS PER MILLION B.T.U.

$$\text{Lb. per gal.} = \frac{140 \times 8.33}{130 + \text{Deg. Bé.}} = (C) = (B)$$

$$\text{B.t.u. per gal.} = \text{B.t.u. per lb.} \times \text{lb. per gal.} = (D) = (A) \times (C)$$

$$\text{Cents per million B.t.u.} = \frac{\text{Cents per gal.} \times 1{,}000{,}000}{\text{B.t.u. per gal.}} = (F) = \frac{(E)}{(D)}$$

EXAMPLE: Deg. Bé. = 23.5; B.t.u. per lb. = 18,000; cents per gal. = 15

Lb. per gal. = (140 × 8.33)/(130 + 23.5) = 7.6

B.t.u. per gal. = 18,000 × 7.6 = 137,000

$$\text{Cents per million B.t.u.} = \frac{15 \times 1{,}000{,}000}{137{,}000} = 110$$

By Chart: (B) = 23.5 or (C) = 7.6; (A) = 18,000; (E) = 15

First step: (D) = (A) × (C) = 137,000

Second step: (F) = (E)/(D) = 110 (check)

for No. 3 of about $1.75 per ton, and with wholesale prices estimated at 63 per cent of low-volatile bituminous. Retail users of heat are normally supplied with manufactured gas, kerosene, or gasoline at prices very much higher, as can be quickly checked by the conversion charts Figs. 1, 2, and 3, in terms of cents per million B.t.u. for any price per ton of coal, per cubic foot of gas, or per gallon of oil. To complete the comparison of costs of primary energy a chart (Fig. 4) is added for water power, giving cents per million B.t.u. for any cost per kw., site, investment, and use factor.

PREPARATION OF WORKING FLUID FOR POWER GENERATION

Before any prime mover may begin the process of transforming

energy in one of its primary forms into work, there must first be a suitable working fluid carrying the energy in a form best adapted for the prime mover to work as a transformer.

When the case is that of water power, preparation of the working fluid involves the building of all of the water-collection, storage-control, and conduit system, including draft tube and tailwater disposal, for bringing water to the turbine under the maximum available head and getting it away. The cost of preparation of the working fluid in this case is the fixed charges on this site development, applied to such part of the capacity as represents the average for a year, and expressed in cents per million B.t.u.

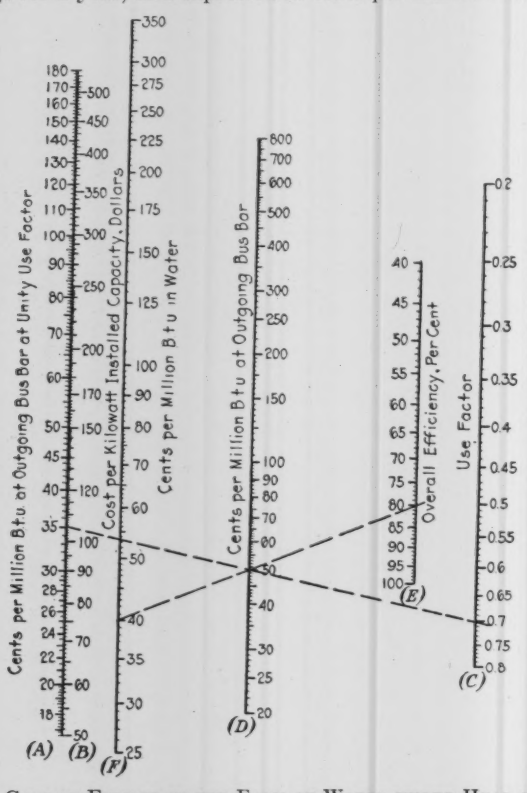

FIG. 4 COST OF ENERGY IN THE FORM OF WATER UNDER HEAD IN CENTS PER MILLION B.T.U. IDENTICAL EQUIVALENT

Cents per million B.t.u. at outgoing bus bar at unity power factor
= cost per kilowatt installed in dollars × 1,000,000 × 100 ÷ (3415 × 8760 × 10)
= (A) = (B)
Cents per million B.t.u. at outgoing bus bar
= cents per million B.t.u. at outgoing bus bar at unity power factor ÷ use factor
= (D) = (B)/(C)
Cents per million B.t.u. in water
= cents per million B.t.u. at outgoing bus bar × overall efficiency
= (F) = (D) × (E)
EXAMPLE: Cost per kw. installed = $105; use factor = 0.7; overall efficiency = 80 per cent
Cents per million B.t.u. at outgoing bus bar at unity use factor
= 105 × 1,000,000 ÷ (3415 × 8760 × 10) = 35
Cents per million B.t.u. at outgoing bus bar = 35/0.7 = 50
Cents per million B.t.u. in water = 50 × 80/100 = 40
By Chart: (B) = 105; (C) = 0.7; (E) = 80; (A) = 35; (D) = 50; (F) = 40; (check)

When the case is that of steam power, preparation of the working fluid involves the making of superheated steam and its delivery to the turbine. In this case the cost of preparation of working fluid is the cost of making and delivering superheated steam, all charges being expressed in cents per million B.t.u. There are three items of cost increment making up this total: first, that due to energy losses; second, that of fixed charges on the investment for necessary equipment; and third, the disbursements incident to operation and maintenance of equipment.

Finally, for oil engines there is no cost for preparation of working fluid, because such engines take oil as delivered and atmospheric air without any preparation, and while the working fluid is actually hot gas, it is not possible to separate the costs of the two functions of converting oil and air into hot gases from that of transforming the heat of hot gases into work.

It is possible to estimate the costs of these two typical modes of preparing the working fluid for steam and for hydraulic turbines, and such estimates are very useful, especially in establishing the relative importance of each variable and comparing the total with that for Diesel fuel oil ready for use.

Water-collection costs for hydraulic turbines are all fixed charges, and these will be evaluated arbitrarily at a yearly rate of 10 per cent without any attempt being made to analyze the justification for this rate, except to point out that it is lower than the rate of 12 per cent for steam-plant equipment and 13 per cent for oil engines, which relations have been adopted as fairly representative of somewhat divergent general opinions.

Investment for water collection includes disbursements for land and fixed structures having a certain capacity in second-feet of water at a given head equivalent to a horsepower capacity, all of which is never used for the 8760 hours of a year. Whether the use is less than capacity because of shortage of water at times or because there is no demand for the power that could be developed at a given time, i.e., light load, is immaterial as to the evaluation of the charges, which for present purposes will be estimated for 40 per cent of capacity over the year. The investment in dollars for any one site development does of course vary with topographical and other natural conditions, and this makes it difficult to arrive at indicative values that might be acceptable as typical of the hydro system. For present purposes, however, values for equipment, hydraulic and electrical, including building, are based on Rush-

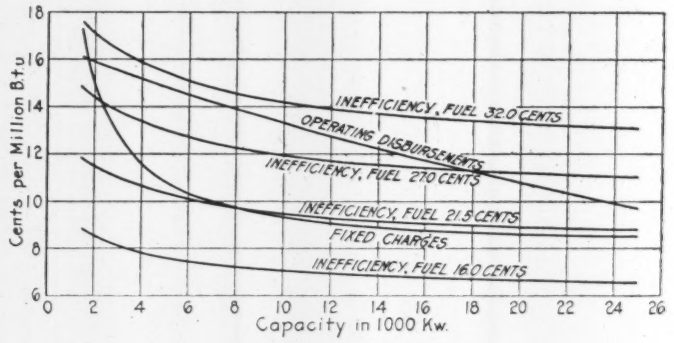

FIG. 5 PREPARATION OF WORKING FLUID—COST INCREMENTS FOR STEAM-TURBINE PLANTS IN CENTS PER MILLION B.T.U.
(Fixed charges, 12 per cent; use factor, 40 per cent.)

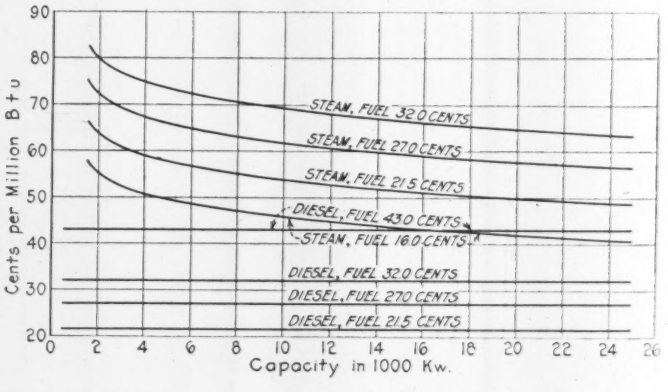
Cents per Million B.t.u.
STEAM, FUEL 32.0 CENTS
STEAM, FUEL 27.0 CENTS
STEAM, FUEL 21.5 CENTS
DIESEL, FUEL 43.0 CENTS
STEAM, FUEL 16.0 CENTS
DIESEL, FUEL 32.0 CENTS
DIESEL, FUEL 27.0 CENTS
DIESEL, FUEL 21.5 CENTS
Capacity in 1000 Kw.

FIG. 6 STEAM TURBINES VS. DIESEL ENGINES—COST OF ENERGY OF WORKING FLUID IN CENTS PER MILLION B.T.U.
(Fixed charges: Steam plant, 12 per cent; Diesel plant, 13 per cent; use factor, 40 per cent.)

more's curves, and site development estimated as one, two, or three times the equipment costs for 20 ft. head; two, three, and four times for 120 ft. head; and three and four times for 400 ft. head. The whole plant-investment cost per kilowatt of capacity is given in Table 13 in the usual form, with corresponding power cost in cents per kw-hr. These totals are segregated into the main process stages in Table 14, giving in cents per kw-hr. the cost of preparation of working fluid, transformation of energy of working fluid into b.hp. energy, and b.hp. energy into electrical. From this latter table the figures for the first process are converted into equivalent cost of preparation of working fluid, cents per million B.t.u. in Table 6, the last part (C) of which is concerned with the hydraulic turbine.

These values for cost of energy of working fluid for hydraulic turbines are directly comparable in kind with those for cost of energy of steam at the steam turbine which have been worked out for four-

fuel costs, namely, 16.0, 21.5, 27.0, and 32.0 cents per million B.t.u., corresponding nearly to coal at $4.50, $6.00, $7.50, and $9.00 per ton (2000 lb.). These steam-energy costs of Table 6 are worked out from the usual form of steam-power-plant investment and power costs given in Table 15, through the process cost segregation of Table 16.

Both of these sets of values in Table 6 for cost of preparation of working fluid for hydraulic and for steam turbines, are directly comparable with the cost of fuel oil for Diesel oil engines directly available and here taken as one-third higher than the purchase price of coal to conform to fair stable conditions in the northeast settled sections of the country.

To make the comparison most useful, plant capacity is made a prime variable, and seven capacities, 1500 kw. to 25,000 kw., are estimated for turbines, steam and hydraulic, with five for Diesel oil engines, air-injection, single-acting vertical, 500 kw. to 3500 kw., the maximum here being set by available catalog sizes—which are being increased. This brings out the effect of size on costs in the range where it has most effect, and also the corresponding effect of varying efficiencies which vary less in sizes beyond those used, in the case of steam, while oil-engine efficiencies remain constant and hydraulic turbines approach this more than steam. In all cases it is assumed that the load is the same, so that the average efficiencies are less than best by an amount calculated from the average unit load and number of units in service, with always one main generating unit as a spare. The other details of the plant equipment must be omitted for lack of space, but it is believed that the figures are fairly representative.

Referring to the figures of Table 6, it appears that the working fluid for hydraulic turbines is in general more costly by a considerable margin, with steam next, and the energy for Diesel oil engines in the form of fuel oil cheapest, even when charged at rates much higher than the one-third excess over coal that has been found to be fairly representative of competitive stability in the northeast. The totals of cost of working fluid are shown graphically in Fig. 6 against a base of plant capacity to bring out clearly the relation of one system to the others.

It is only in the case of steam that the preparation of working fluid involves a loss of energy with a corresponding inefficiency increment of cost in addition to the increments of investment and operating disbursement. This inefficiency increment is not shown in Table 6 directly, as the "Energy Loss Item" is the previous cost divided by the efficiency, which is the cost added to the inefficiency increment, this latter being found by subtracting the fuel cost from the tabular value. The inefficiency cost increment thus found is as in Table 7.

Comparing the three cost increments, plotted in Fig. 6, it appears that they are approximately equal for the most expensive coal—$9 per ton—and for the smallest plant—1500 kw.—but for the same fuel in larger plants the fuel increment falls less than the other two. Both the investment and operating-disbursement increments fall to almost half the value at 25,000 kw., the former exactly, the latter not quite, while the inefficiency increment falls only 20 per cent. This indicates that while higher efficiency in steam making in a 1500-kw. plant would considerably reduce the fuel increment of cost with the expensive fuel, it cannot be justified at much if any increase in investment or operating disbursements, while in a 25,000-kw. plant, material increases in either or both of these items would be justified. On the other hand, with the cheapest fuel—$4.50 coal—there would be an exception. That is, any efficiency gains must be without other expense if the net result is to be a saving in total energy cost.

For example: Assuming a change in boiler plant that adds 2 per cent to the efficiency, 10 per cent to investment costs, and a 5 per cent increase in operating disbursements total for steam energy, it is possible to determine readily if the change is justified.

TABLE 5 ENERGY COST IN FUEL DELIVERED

Place	Coal: Dollars per ton	Coal: B.t.u. per lb.	Coal: Cents per million B.t.u.	Oil: Cents per gal.	Oil: Lb. per gal.	Oil: B.t.u. per lb.	Oil: Cents per million B.t.u.	Ratio of costs per million B.t.u. oil to coal
Pittsburgh	3.10	13,000	12.0	6.0	7.1	19,750	43.0	3.68
Oil City	4.13	13,000	15.9	6.0	7.1	19,750	43.0	2.70
Cumberland	3.84	14,600	13.2	....	....	....	....	....
Philadelphia	7.00	14,600	24.0	3.85	7.67	19,000	26.5	....
Philadelphia	6.25	14,600	21.4	4.35	7.29	19,450	31.0	1.17 to 2.06
Philadelphia Anth...	3.84	12,000	16.0					
Philadelphia Anth...	4.35	12,000	18.1					
Duluth	6.50	13,000	25.0	....	....	.....	39.0	1.36 to 1.56
	8.00	14,000	28.7					
	6.25	11,500	27.2					
Minneapolis	4.55	12,000	19.0	4.89	7.52	19,210	34.0	1.8 to 1.9
	4.85	13,000	18.6					
New York	7.50	14,400	26.0	4.50	7.29	19,000	32.0	1.23
	6.50	14,400	22.6	5.50	7.29	19,000	39.0	1.73
Chicago	4.20	12,750	16.5	7.25	6.98	19,500	53.0	2.94 to 3.22
	4.65	12,500	18.6	6.75	6.98	19,500	50.0	
	4.85	12,500	19.4	5.06	7.52	....	....	
	4.45	12,200	18.2	5.06	7.38	....	....	
	4.60	13,000	17.7	7.00	6.98	19,500	51.0	
	4.20	12,000	17.4	....	....	....	....	
Denver	2.00	10,000	10.0	4.76	8.33	18,380	31	3.1
El Paso	5.70	12,500	22.8	5.7	7.67	19,000	39	1.71

TABLE 6 PREPARATION OF WORKING FLUID FOR PRIME MOVERS—POWER COSTS BY PROCESS STAGES IN CENTS PER MILLION B.T.U.

(Continuous 24-hour service. Average yearly load, 40 per cent)

A—STEAM TURBINES (Fixed-Charge Rate, 12 per cent)

Plant capacity, kw	1,500	2,500	5,000	10,000	15,000	20,000	25,000
Efficiency, per cent	64.50	65.65	67.50	69.33	70.20	70.68	71.00
Energy Loss Item:							
Fuel price per million B.t.u. 16.0 cents	24.81	24.37	23.70	23.07	22.74	22.64	22.53
Fuel price per million B.t.u. 21.5 cents	33.33	32.75	31.85	31.01	30.62	30.42	30.28
Fuel price per million B.t.u. 27.0 cents	41.86	41.12	40.00	38.95	38.46	38.20	38.03
Fuel price per million B.t.u. 32.0 cents	49.61	48.74	47.41	46.16	45.58	45.28	45.07
Operating disbursements	15.60	15.30	15.10	13.70	11.80	10.75	9.70
Fixed charges	17.30	13.75	10.85	9.15	8.95	8.60	8.50
Total:							
Fuel price per million B.t.u. 16.0 cents	57.71	53.42	49.65	45.92	43.54	41.99	40.73
Fuel price per million B.t.u. 21.5 cents	66.23	61.80	57.80	53.86	51.37	49.77	48.48
Fuel price per million B.t.u. 27.0 cents	74.76	70.17	65.95	61.80	59.21	57.55	56.23
Fuel price per million B.t.u. 32.0 cents	82.51	77.79	73.36	69.01	66.33	64.63	63.27

B—DIESEL OIL ENGINES (Fixed-Charge Rate, 13 per cent)

Plant capacity, kw	500	1,000	1,500	2,500	3,500
Fuel Directly Available:					
Price per million B.t.u. 21.5 cents	21.5	21.5	21.5	21.5	21.5
Price per million B.t.u. 27.0 cents	27.0	27.0	27.0	27.0	27.0
Price per million B.t.u. 32.0 cents	32.0	32.0	32.0	32.0	32.0
Price per million B.t.u. 43.0 cents	43.0	43.0	43.0	43.0	43.0

C—WATER POWER (Fixed-Charge Rate, 10 per cent)

	1,500	2,500	5,000	10,000	15,000	20,000	25,000
Plant capacity, kw							
Total = Fixed Charges on Site:							
20 ft. Head, Site = 1.0 × Equip.	41.774	38.993	37.234	36.253	36.029	36.642	37.023
20 ft. Head, Site = 2.0 × Equip.	83.548	77.986	74.468	72.506	72.058	73.284	74.046
20 ft. Head, Site = 3.0 × Equip.	125.322	116.973	111.702	108.759	108.087	109.926	111.069
120 ft. Head, Site = 2.0 × Equip.	39.634	39.676	36.601	33.677	31.937	31.449	31.069
120 ft. Head, Site = 3.0 × Equip.	59.452	59.514	54.901	50.516	47.905	47.174	46.603
120 ft. Head, Site = 4.0 × Equip.	79.269	79.352	73.202	67.358	63.874	62.899	62.137
400 ft. Head, Site = 3.0 × Equip.	51.420	48.812	44.240	38.593	36.338	35.480	35.308
400 ft. Head, Site = 4.0 × Equip.	68.560	65.083	58.986	51.457	48.451	47.307	47.078

TABLE 7 PREPARATION OF WORKING FLUID FOR STEAM TURBINES

INEFFICIENCY COST INCREMENT IN CENTS PER MILLION B.T.U.

	1,500	2,500	5,000	10,000	15,000	20,000	25,000
Plant capacity, kw							
Fuel cost per million B.t.u. 16.0 cents	8.81	8.37	7.70	7.07	6.74	6.64	6.53
Fuel cost per million B.t.u. 21.5 cents	12.83	11.25	10.35	9.51	9.12	8.92	8.78
Fuel cost per million B.t.u. 27.0 cents	14.86	14.12	13.00	11.95	11.46	11.20	11.03
Fuel cost per million B.t.u. 32.0 cents	17.61	16.74	15.41	14.16	13.58	13.28	13.07

TABLE 8 PREPARATION OF WORKING FLUID FOR STEAM TURBINES

COMMERCIAL EFFICIENCY, PER CENT

	1,500	2,500	5,000	10,000	15,000	20,000	25,000
Plant capacity, kw							
Fuel cost per million B.t.u. 16.0 cents	27.7	30.0	32.3	34.8	36.8	38.2	39.4
Fuel cost per million B.t.u. 21.5 cents	32.5	34.8	37.3	40.0	42.0	43.2	44.5
Fuel cost per million B.t.u. 27.0 cents	36.2	38.4	41.0	43.7	45.5	46.9	48.8
Fuel cost per million B.t.u. 32.0 cents	38.7	40.6	43.6	46.3	48.2	49.5	50.6

THERMAL EFFICIENCY, PER CENT

All fuel prices	64.5	66.65	67.5	69.33	70.20	70.68	71.0

Take first the smallest plant, 1500 kw., and the cheapest coal. For this condition the costs would be

	Cents per million B.t.u.
Energy loss item	24.10
Operating disbursements	16.38
Investment fixed charges	19.03
Total	59.51

As the total is 59.51 cents against 57.71, it is clear that the change is not justified. Applying the same conditions to the 25,000-kw. plant, the new cost would be

	Cents per million B.t.u.
Energy loss item	22.00
Operating disbursements	10.18
Investment fixed charges	9.35
Total	41.53

Here again the total, 41.53 cents, is greater than it was before, 40.73, so for this low-priced fuel (16 cents per million B.t.u.) such a change would not be justified in a plant of any size within these ranges.

For the high-priced fuel (32 cents per million B.t.u.), the figures for 1500 kw. would be

	Cents per million B.t.u.
Energy loss item	48.20
Operating disbursements	16.38
Investment fixed charges	19.03
Total	83.61

This total, 83.61 cents, being greater than it was, 82.51, indicates again that the change is not economical. Finally, for 25,000 kw. the costs are

	Cents per million B.t.u.
Energy loss item	44.00
Operating disbursements	10.18
Investment fixed charges	9.35
Total	63.53

Here the total, 63.53 cents, while larger than it was, 63.27, is much closer, so that while the change is not justified it permits the conclusion that for a somewhat larger plant with this 32-cent fuel it would be justified.

Many other problems concerning the value of efficiency may be quickly and conclusively answered in this way, provided there are available reliable statistical data on investment and operating costs. Without such data no one by any process can possibly judge the value of efficiency in the sense of being able to say that increase of process efficiency will raise or lower the commercial efficiency.

For the data here used the commercial efficiency may be determined by dividing the cost of input energy by the cost of output energy as in Table 8. For any change in thermal efficiency to be justified there must be an increase in commercial efficiency.

FURTHER POSSIBILITIES OF THE METHOD

By an extension of the same method it is possible to investigate to greater advantage two additional sets of questions of importance in connection with the generation and delivery of steam to turbines. The first of these is the distribution of the expense totals here given among the several individual successive processes involved, and for each the relative magnitude of the three increments of inefficiency, investment, and operating disbursements. This will show more precisely where economies are most likely, and by what treatment: reduction of operating disbursements or of investment, or increase of efficiency. The second of these is the probability of value without actual figures, or the exact prediction of value with figures, for any one or more of the now discussed efficiency gains in steam generation and transmission to turbine, or the corresponding value of increased capacity even with decreased efficiency.

Taking up the first of these questions, it is clear that the overall process of steam generation, including delivery, here considered is divisible into a series of which the following will serve as an illustration:

PROCESS STAGES OF STEAM GENERATION, INCLUDING DELIVERY

FIRST STAGE—*Process:* Transfer of fuel from point of receipt to stoker hopper, including storage.
Cost: Cents per million B.t.u. in fuel at the stoker hopper.

SECOND STAGE—*Process:* Feeding fuel to furnace, burning fuel, supplying air, removal of flue gases, and removal of ash, including disposal.
Cost: Cents per million B.t.u. in hot gases in furnace available for absorption by boiler.

THIRD STAGE—*Process:* Feeding water to boiler, heating water, making and superheating steam by hot gases from furnace.
Cost: Cents per million B.t.u. in steam at the boiler nozzle.

FOURTH STAGE—*Process:* Steam distribution by pipe system to the turbines.
Cost: Cents per million B.t.u. in steam at the turbine.

In proportion as these costs are known, and for each of them the energy losses or efficiencies with the three cost increments, (*a*) inefficiency increment, (*b*) investment increment, and (*c*) operating disbursement increment, so can the value of every change be accurately estimated and especially the value of an efficiency change.

It is possible to subdivide further whenever it is desirable to do so. For example, cost of delivery of coal to hoppers can be divided into a transportation and a storage item. Cost of generating heat in furnaces can be divided into cost of coal feed, ash removal, ash disposal, combustion proper, and draft; while draft itself can be divided into air supply, forced draft, induced draft by stack or fans, flue transmission of gases, and cinder removal. Cost of boiler heat absorption can be divided into boiler-feedwater pumping, feedwater heating (as a credit), steam making, and superheating. Even steam distribution is divisible into transfer of steam and protection of piping against loss of heat.

Auxiliaries are chargeable to any one process or series of processes in two ways, whether steam or electrically driven. The first is to charge the steam or electricity used at the cost in cents per million B.t.u. at the point of the system where taken. This is equivalent to treating this auxiliary energy the same as consumable supplies like lubricating oil. The second is to introduce efficiencies corresponding to the energy abstracted for auxiliary operation. If all costs are correctly determined, the results will be the same either way. It will be found, however, that the former is simpler and clearer.

For some determinations of the value of efficiency it is best to use the most detailed segregation of processes with respective costs, but the contrary is true where the effect can be determined only by including all the stages of an inclusive series broad enough to embrace every effect. An example of the latter is the boiler itself. While thermally, water heating, ebullition, and superheating are separate and distinct processes, they are not in fact as carried out in a boiler, nor can the separate efficiency of each be determined. This situation is especially important and necessary to recognize in those cases where two or more stages of a process in series are dependent as regards efficiencies—that is, where a change in one affects the next in a way that is indeterminate quantitatively though it may be qualitatively. This is the case with nearly every factor of boiler design, and in connection with boiler design with one or more auxiliary matters. For example, boiler-air preheating by flue gases is known to increase boiler efficiency more than the equivalent of the waste heat returned, because of the improved heat absorption of the boiler due partly to hotter gases and partly to more rapid combustion with less unburnt gases passing between the boiler tubes. The lower flue-gas temperature also leaves less heat available for an economizer. While matters of this kind—and there are many such—are qualitatively clear, it is quite impossible to numerically divide the effects except by test. In all such cases the commercial-efficiency determination must be made for the whole series, inclusive of all the interchanging effects, and for the above example "steam making" is such an inclusive process. *When this is done, it will be found that many so-called economies which are so easily demonstrated thermally by manipulation of steam tables and thermodynamical relations, are not economies at all, but are additional expenses.*

(To be concluded in the July issue)

[Dr. Lucke's paper formed an important feature of the program carried out at various section meetings throughout the country during Gas Power Week (April 21–27). On account of its length only the first half has been presented above. The remainder will be published in the July issue.—Editor.]

The Generation and Utilization of Steam in the Iron and Steel Industry

By JOHN A. HUNTER,[1] PITTSBURGH, PA.

This paper describes the equipment employed in the iron and steel industry for generating and using steam. Quantities and cost of fuel, and the cost of converting the heat in the fuel to steam are shown. Present-day tendencies toward the design and size of equipment, as well as refinements in control, are indicated. A brief description of two of the latest installations is given. The probable savings which could be made if all of the steam required in the industry were made and consumed in the most efficient apparatus now in use are also shown. Because of the scope of the subject it has been impossible to cover the various features in much more than general terms.

IT IS the purpose of this paper to describe the type of equipment employed for the generation and use of steam in the iron and steel industry, the operation of the equipment, the utilization of waste heat, and also the savings which would be realized if all the steam were generated and used in the best type of equipment available in the industry.

To generate steam for all purposes, approximately 16,150,000 gross tons of coal and blast-furnace gas equivalent to 6,050,000 gross tons of coal are used each year, or a total of 22,200,000 gross tons of fuel. At an average price of $4 per gross ton the cost is $88,800,000. To convert this fuel into steam costs $38,870,000, making the total cost of generating steam $127,670,000. The rated capacity of the boilers used to generate the steam is about 2,650,000 hp. The steam is used in approximately 8600 prime movers having a rated capacity of 4,900,000 hp., and for process work. About 4.3 lb. of coal is required to produce a brake horsepower-hour.

Boilers, Superheaters, Feedwater, Etc.

Boilers. One of the most important factors in determining the type of boilers has been the quality of the feedwater. All plants, except a few favorably located near the Great Lakes, get their water from rivers, small streams, or wells. These waters are nearly always high in sediment and incrusting solids, and at times are corrosive. With this kind of feedwater frequent washing and turbining are necessary. Another factor is the use of uncleaned blast-furnace gas. Due to these conditions the vertical or inclined-tube boiler has been quite generally used because of its lack of header caps, ease of removing tubes, and ease in keeping the gas passages free from accumulations and the baffles tight.

Table 1 shows the number, type, and size of boilers used by several of the largest steel companies, and is probably representative of the entire industry.

TABLE 1 CLASSIFICATION OF BOILERS

	Percentage of Total Number Classified[1]				
	250 hp. and below	Above 250 hp. to 500 hp.	Above 500 hp. to 1000 hp.	Above 1000 hp.	Total
Vertical water-tube	25.6	34.0	3.6	0.1	63.3
Horizontal water-tube	15.6	11.0	0.9	0.7	28.2
Return tubular	8.5	....	....	....	8.5
Percentage of each size	49.7	45.0	4.5	0.8	100.0

[1] Total number of boilers classified, 2799.

The boilers which are now being installed will probably average 800 hp. per unit, the maximum size being about 2000 hp. The vertical and inclined-tube types are still the most popular. They are constructed for a maximum pressure of 300 lb.; however, 200 lb. is the pressure for most installations.

The boilers are generally being enclosed in solid firebrick settings, with ample furnace volumes to give complete combustion at high ratings.

Superheaters. Probably 15 per cent of the present boilers are equipped with superheaters for an average of 75 to 100 deg. fahr. superheat. Practically all new boiler installations include superheaters to yield an average superheat of about 100 deg. fahr., with maximums of 200 deg. fahr.

Economizers. Economizers have been installed to a limited extent, not over 10 per cent of the total boiler capacity being equipped. Most of the installations have cast-iron tubes and are of the separate type. The recent installations are of the integral type with either cast-iron or steel tubes.

Stokers. Of the coal-fired boilers probably 75 per cent are equipped with stokers. Most of the older installations are natural-draft chain grates. Recent installations are practically all forced-blast, of the underfeed or chain-grate types.

Powdered Coal. Powdered coal has not been used to a great extent. In some works where it is used for metallurgical purposes it is also used under boilers. Recently several boiler plants having a total rated capacity of 15,000 to 20,000 hp. have been equipped to use powdered coal from individual pulverizers. Some works are also using powdered coal to supplement blast-furnace gas.

Feedwater. Table 2 shows in a general way the character of the water used in the principal steel centers of the country. The quality of the water available is gradually getting worse due to increasing contamination by municipal and industrial wastes. This, together with the demand for increased ratings from the boilers, has led to a very general installation of purifying systems. There are now in operation from 150 to 175 of these systems and they treat the feedwater for from 60 to 70 per cent of the total boiler capacity. Of these about 65 per cent are of the intermittent type.

TABLE 2 TYPICAL FEEDWATERS

Source	Grains per U. S. gallon—Total solids	Grains per U. S. gallon—Incrusting solids	Cost of reagents to treat 1000 gal., cents
Monongahela River	9 –35	6–20	2 – 8
Ohio River (Upper)	7 –20	5–15	2 – 5
Mahoning River	15 –35	10–25	3 –10
Lake Erie and Niagara River	7½–10	6– 8	2½
Cuyahoga River	20 –40	10–20	2½– 5
Lake Michigan	10	7	2
Schuylkill River	8 –16	6–13	2½– 3½
Birmingham Creeks	12 –25	8–15	2½– 3½

Auxiliary Equipment

Auxiliary equipment is largely steam-operated, particularly in the older installations. The reciprocating-type feed pump is used to the greatest extent, but practically all recent installations are of the centrifugal type, both motor- and turbine-driven. Stokers and fans in the older installations are driven by small engines; for the new installations motors and turbines are employed.

Soot blowers have been installed quite generally in the last few years and are now commonly considered an essential part of a new boiler installation.

Practically all boilers are equipped with feedwater regulators, the continuous-flow type being most commonly used.

Damper regulators which are operated by changes in steam pressure are quite extensively used, and, to a limited extent, regulators controlled by the furnace pressure. In most stoker installations the regulator also controls the speed of the stoker and fan.

The earlier regulators gave only two positions, either wide open or entirely closed. Those now being installed give intermediate positions corresponding to the demand on the boiler plant.

The steel industry has been a pioneer in the development of regulating equipment, and still employs automatic control to a greater extent than central-station plants.

Meters for the measurement of the boiler feedwater are used by the largest steel companies. Each boiler plant is equipped with a meter, generally of the venturi type, the records from which are used to determine the output of the plant.

Recording pressure gages and feedwater-temperature thermometers are used in practically all plants.

[1] Steam and Sanitary Engineer, American Sheet & Tin Plate Co. Mem. A.S.M.E.

Contributed by the Power Division and presented at the Spring Meeting, Cleveland, Ohio, May 26 to 29, 1924, of The American Society of Mechanical Engineers. All papers are subject to revision.

Automatic machines for determining the carbon dioxide in the flue gases are not employed to a great extent, their use having been curtailed owing to the difficulty of keeping them in operation. The air-flow meter due to its simplicity is taking its place.

Steam-flow meters are extensively used. Some of the larger companies are installing a meter on each boiler which indicates and records the steam produced. Meters which give a graphic record of the steam flow, air flow, and stack temperature on the same chart are becoming more popular.

Non-return valves are used on practically all boilers as a safety feature.

A brief description of the best representative coal- and blast-furnace-gas-fired boiler plants from which efficiencies of 80 per cent and higher are being obtained, is given in the Appendix.

Organization and Operation

With a few exceptions those in direct charge of the boilers are practical men who have come up from the ranks. In some of the more progressive companies technically trained men have direct supervision of the operations. However, in most all large companies there is a technically trained man in charge of a department that has general supervision of the generation and use of steam.

Quite generally complete records of operation are kept. In many of the largest companies comparative cost sheets are prepared each month showing the cost of producing steam, efficiency, etc., for each boiler plant.

Table 3, given in the Appendix, shows comparative costs for boiler plants which represent the average and best coal- and gas-fired plants. It has been prepared on the form used by several of the largest companies and shows that the average coal-fired boiler plant is generating a boiler horsepower-month (730 boiler hp-hr.) for $8.30 and the best for $5.68. The cost at blast-furnace-gas-fired plants is $7.34 for the average and $4.93 for the best per boiler horsepower-month (730 boiler hp-hr.). These costs are all based on an average fuel price of $4 per gross ton.

The average output obtained from boilers in operation is about 110 per cent of rated capacity. Recent installations are operated at a continuous rating of 150 to 200 per cent of rated capacity. These ratings may seem low compared to those obtained from central-station boilers, but in making such a comparison the operating conditions must be considered. In central-station boilers, condensed steam with a slight percentage of make-up water is used for feed purposes. In steel works the steam is ordinarily used at widely separated points which are so far from the source that it is impracticable to return the condensate, consequently the feed-water contains more or less incrusting solids. The high ratings obtained from central-station boilers are seldom continuous throughout the twenty-four hours, while in steel works the load is fairly constant for six days per week.

The average steam pressure carried is about 140 lb. gage; the maximum pressure, about 300 lb. gage.

The feedwater is heated in open heaters to an average temperature of 180 to 210 deg. fahr. with exhaust steam from boiler auxiliaries. In recent installations where the auxiliaries are motor-driven, steam is bled from bleeder-type turbines for heating the feedwater.

The average boiler efficiency is about 60 per cent.

The large steel works have quite extensive piping systems. Main pipe lines from 16 to 24 in. in diameter and 2500 to 3500 ft. long are in use. All boiler plants of one works are generally connected into one system. Steam velocities of 6000 to 8000 ft. per min. are commonly used. The joints are mostly of the Van Stone type, and in recent installations the flanges are welded together to prevent leakage. The pipe and flanges are insulated with a covering about 2 in. thick.

Prime Movers

Table 4 of the Appendix shows the number and horsepower of prime movers for the years 1909, 1914, and 1919. In 1919 there were 6796 steam engines having a total capacity of 3,243,347 hp. or an average capacity of 478 hp., and 922 turbines of a total capacity of 863,026 hp., or an average of 936 hp. Although the total rated capacity of steam prime movers increased 37 per cent from 1909 to 1919, the total number decreased 8.5 per cent and the rated capacity decreased from 91.3 per cent to 76.0 per cent of the total capacity of all prime movers. Internal combustion engines show some increase, but the greatest increase has been in the use of electric power. The total capacity of motors increased from 851,752 hp. in 1909 to 2,593,150 hp. in 1919, or over 200 per cent. The use of purchased power shows an even greater increase, more than 900 per cent, which would indicate not only a pronounced tendency toward electrification, but also toward the use of central-station power.

The size and kind of engines in use vary widely, practically every known type being represented. They are both condensing and non-condensing, most of the larger engines being compound condensing.

The turbine is used quite extensively, in small sizes to drive fans and pumps, and in the larger sizes to drive generators.

There has been only one installation of a turbine for driving a mill, and that was made in about 1914 by the Carpenter Steel Company. This installation—a low-pressure turbine—was described in a paper by J. D. Berg,[1] and is still in successful operation.

Two of the largest manufacturers of turbo-generators have sold to the iron and steel industry 334 units varying in size from 300 to 17,000 kw. and having a total capacity of 908,425 kw., of which 39 per cent has been installed since 1918.

The first use of the turbo-blower for a blast furnace was made in 1909 by the Empire Iron and Steel Company, at Oxford, N. J. There are now about 70 turbo-blowers in use, of which seven are for bessemer converters and the remainder for blast furnaces. These machines vary in size from 20,000 to 60,000 cu. ft. of air per min. An average size of unit for blowing a blast furnace would be 50,000 cu. ft. per min. at 16 lb. pressure. The water rate of these machines is about the same as that of a compound condensing engine. In the last five years, of 22 blowing units installed 20 were of the turbo type, the other two being reciprocating steam engines.

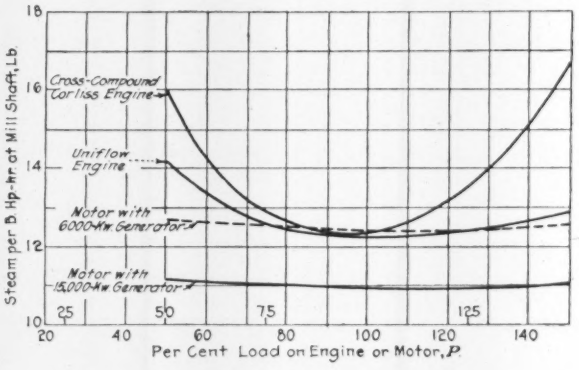

FIG. 1 TYPICAL WATER RATES FOR STEAM ENGINES AND TURBO-GENERATORS

(For 2000-hp. engines and motors. Steam pressure, 275 lb. per sq. in.; superheat 200 deg. fahr.; engines and turbo-generators operated condensing.)

Turbines also seem to have replaced the large gas engines for driving generators, for since 1918 only five gas engines, having an aggregate capacity of 21,140 kw., have been installed.

Although these figures indicate an increased use of turbo-generators and motor drives, the development of the uniflow engine has been responsible for the installation of a great many steam engines. This engine is particularly adapted to mill drives on account of its economy with variable loads and its large overload capacity. The curves in Fig. 1 show typical water rates per delivered horsepower at mill shaft for uniflow and compound engines, and for 6000- and 15,000-kw. turbo-generators with motor drives for mills.

These curves show clearly the advantage of the uniflow engine over the compound engine for variable loads. At full load the difference in the water rate is slight, but as the load changes the difference in favor of the uniflow becomes greater and is quite large at low and high ratings. The uniflow engine has a better water rate from about $^3/_4$ load to $1^1/_4$ load than the 6000-kw. turbo-generator with motor drive. The curve for the 15,000-kw. unit shows the effect of increasing the size of the turbo-generator.

Several recent studies made to determine the most economical mill drive would indicate that in general, when all conditions are

[1] Trans. Engrs. Soc. W. Pa., 1914.

considered, the uniflow engine is more economical for works where the capacity of the turbo-generator is less than about 6000 kw.

Two manufacturers of large uniflow steam engines have sold to steel works 20 such engines for mill drives in the last few years. One of the recent installations drives a reversing blooming mill. As it is the first application of this character, a brief description of it may be of general interest. It is a four-cylinder, four-crank horizontal engine. The cylinders are each 34 in. in diameter by 60 in. stroke. Its normal operating speed is 150 r.p.m. and it is capable of reversing from 90 r.p.m. forward to 90 r.p.m. backward in three seconds. The steam conditions are 240 lb. pressure, 150 deg. fahr. superheat, and 26 in. vacuum. It is expected that the steam consumption will be 300 lb. per ton of steel rolled when making nine elongations of an ingot 19 in. by 25 in. weighing 8300 to 8500 lb.

The uniflow engine is also being employed quite extensively to drive small generators up to 400 kw., particularly for non-condensing operation. For condensing operation, for units of 500 kw. and larger, turbines are being used, having one stage of bleeding to supply steam for heating feedwater and buildings.

Waste-Heat Utilization

Within the last few years the utilization of waste heat has been given a great deal of consideration, as is shown by the kind of equipment being installed for that purpose. The largest source of waste heat is blast-furnace gas. In 1919 enough of this was used for operating gas engines and producing steam to replace 7,259,878 gross tons of coal. Of this, 1,204,821 gross tons coal equivalent was used in gas engines, leaving 6,055,057 gross tons coal equivalent used for producing steam.

By-product coke-oven gas is used to some extent for producing steam, but this gas is too valuable a fuel to be used for steam purposes and is generally used in open-hearth and heating furnaces. In some places it is used over Saturdays and Sundays for generating steam.

The first installation of a boiler to utilize the waste heat in the flue gases from open-hearth furnaces was made in 1910, at the South Chicago Works of the Illinois Steel Company. A description of this installation and of its development is covered in a paper by C. J. Bacon.[1] In 1919 there were approximately 140 open-hearth furnaces equipped with boilers, and waste heat equivalent to 500,000 gross tons of coal was recovered.

There are also some installations of boilers and economizers on heating furnaces, but the total number is probably not very great and the aggregate heat recovered is not large.

Coke breeze—waste fuel from coke ovens—is used for the production of steam. The development of the forced-blast chain-grate stoker has made it possible to burn this fuel efficiently. However, the total amount used is relatively small.

At present the iron and steel industry is producing power at an average rate of 56,000 B.t.u. or 4.3 lb. of coal per b.hp-hr., and the best practice is at the rate of 18,000 B.t.u. or 1.4 lb. of coal per b.hp-hr. This compares with an average of 26,000 B.t.u. or 2.0 lb. of coal per b.hp-hr. for all central-station plants, and of 14,800 B.t.u. or 1.1 lb. of coal for the best central-station plants.

Some of the reasons why the steel industry is not producing power as economically as central stations are:

Steel companies, as a rule, have a limited amount of capital for development and extension, and the equipment which bears directly on the quality and quantity of product receives the first consideration.

In most works higher pressures cannot be used in the existing equipment, so that the tendency is to put in new equipment for the same steam conditions. However, in many cases the new equipment is constructed for and operated at somewhat higher steam pressures and superheats, and is connected to the old system through a reducing valve.

In the central-station plant power is the product, so that it is necessary for the central station to take immediate advantage of any development which will reduce the cost of power in order to meet competition. In the steel industry power is comparatively a small item in the total cost of a ton of steel; therefore economies in its production do not receive as much attention.

[1] Proc. Am. Iron & Steel Inst., 1915.

However, with the increased cost of coal, possible fuel savings are receiving more attention and efficient equipment is being installed as is illustrated by an installation now being made in a steel works. The following is a brief description of the equipment. Each boiler will have 12,045 sq. ft. of heating surface and an integral economizer having 6740 sq. ft. The boilers are to be fired with blast-furnace gas using surface-combustion burners. The fans will be motor-driven and automatically regulated to maintain a balanced pressure in the furnace. The feedwater will be condensed steam, with evaporators for the make-up water. The main feedwater heater is of the deaerator type. The steam, which will be at 300 lb. pressure and 200 deg. fahr. superheat, will be used in a 12,500-kva. turbo-generator. This plant should produce power at a cost comparable with the better central-station plants.

Possible Savings

The amount of fuel, the type of equipment and the general methods employed in the generation and utilization of steam having been outlined, the author believes that it would be of interest to make a survey of the possible savings which could be made if all the steam were generated and used in the best type of equipment and if waste heat were utilized in the most efficient methods developed. It is assumed that the operating conditions will be as follows:

Steam conditions: 275 lb. pressure, 200 deg. fahr. superheat, and 28 in. vacuum for the turbines

A boiler efficiency of 80 per cent

15,000-kw. turbo-generators or larger with motor drives for the mills

Turbo-blowers for blowing blast furnaces and bessemer converters

Other recoveries of waste heat, such as from open-hearth furnaces, heating furnaces, etc., will be utilized to the same extent as at present.

Fuel Required. Taking the year 1919 as a basis, with a production of 30,543,167 gross tons of pig iron and 33,289,939 gross tons of steel ingots, it is estimated that it will be necessary to produce 10,410,000,000 b.hp-hr. To produce a brake horsepower-hour will require 1.4 lb. of coal or a total of 6,500,000 gross tons of coal.

For process steam and heating buildings 1,670,000 gross tons are required, or a grand total of 8,170,000 gross tons per year for the industry.

Fuel Available. From the blast furnace it has been shown that with the present practice there is available 6,055,000 gross tons of coal equivalent. It is estimated that by stopping bleeder losses and increasing the efficiency of the stoves, 2,345,000 gross tons of additional blast-furnace gas will be made available, making the total coal equivalent of blast-furnace gas 8,400,000 gross tons, which could be used to generate steam. From this it is seen that there is enough waste heat available from the blast furnaces, without considering additional heat from other sources such as open-hearth furnaces, heating furnaces, etc., to produce all the steam required in the industry. This would mean a saving of 16,150,000 gross tons of coal per year, which at an average price of $4 per gross ton equals $64,600,000; also a saving in the cost of operating the boiler plants of $33,140,000, making the total saving per year $97,740,000.

In order to accomplish this desideratum it will be necessary to provide means to utilize the extra power at times and at works where there will be a surplus. This situation exists in several of the large steel centers, and has been solved by installing large turbo-generators and using electric drives for the mills, and connecting several works together with high-tension electric transmission lines. In addition to this, in some cases the power system is connected to a central-station power system and contracts are made for the interchange of power. This arrangement is very advantageous to both parties, and through agreements of this kind it will be possible to utilize the waste heat of the industry to the fullest extent.

The subject is now being studied by several of the large steel and central-station companies and no doubt in the near future most of the large steel works will be tied in with central-station systems. When this is done it will be possible to conserve all of the surplus waste heat from unbalanced works and the heat which is now wasted over Saturdays and Sundays when the finishing mills are not in operation. Through the central-station transmission lines it will be possible to interchange power between works which are

unbalanced, to utilize the surplus power from isolated blast furnaces, and to supply power to isolated finishing mills.

The basic data for fuel used and number and horsepower of prime movers was obtained from the Bureau of the Census, Department of Commerce.

The author desires to express his grateful appreciation for the courteous response of those connected with both manufacturing and operating companies, and also for the assistance rendered by a number of friends and associates in the preparation of this paper.

Appendix

DATA ON REPRESENTATIVE STEEL-WORKS BOILER PLANTS

Coal-Fired Boiler Plant. The plant, shown in Fig. 2, consists of four Stirling boilers constructed for 200 lb. pressure and 140 deg. fahr. superheat; each is equipped with a Foster superheater and Sturtevant economizer. Each unit has a total heating surface of 10,888 sq. ft., divided as follows: Boiler, 6935 sq. ft.; superheater, 735 sq. ft.; economizer, 3218 sq. ft. The boiler is enclosed in a solid firebrick setting and is baffled to give four passes of the gases over the heating surface. Each boiler is equipped with a Harrington forced-blast chain-grate stoker having 143 sq. ft. of grate surface and an American suspended arch. The side and bridge walls are cooled by water boxes connected into the boiler circulation. Soot blowers are used to keep both the boiler and economizer tubes clean.

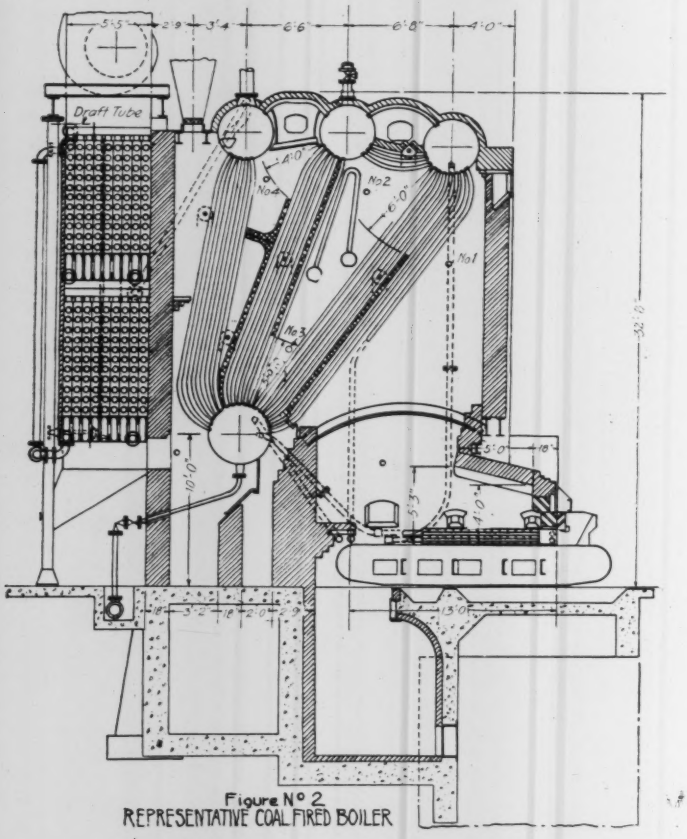

FIG. 2 REPRESENTATIVE COAL-FIRED BOILER

Motors are used to drive the induced- and forced-blast fans and stokers.

Individual steel stacks 48 in. in diameter by 92 ft. high are used. The water level is controlled by a Copes feedwater regulator.

A Hagan regulator controls the speed of the fans and stokers.

A control panel is provided for each boiler, on which is mounted a Bailey meter for steam and air flow, recording thermometers for temperatures of the water and gases entering and leaving the economizer, gages to show the air pressure in the main duct and the different compartments of the stoker, and control apparatus for pressure of the air to each compartment.

Blast-Furnace-Gas-Fired Boiler. In this plant, shown in Fig. 3, there are six Bigelow-Hornsby boilers designed for 275 lb. pressure. Each boiler is ten sections wide and six sections deep, and has a total heating surface of 19,500 sq. ft. The last two sections (6200 sq. ft.) are connected so they can be used as an economizer or as steam-producing heating surface according to the load conditions. This leaves 12,700 sq. ft. of heating surface in the boiler proper.

The baffling provides for straight flow of gases through the first four sections and three passes through the last two sections. Soot blowers are used to clean the tubes.

Each boiler is equipped with individual motor-driven forced- and induced-draft fans. The stacks extend 32 ft. above the fans.

(*Continued on page 342*)

TABLE 3 COMPARATIVE COSTS FOR BOILER PLANTS

[Cost per boiler hp-month (= 730 boiler hp-hr.) based on 13,000-B.t.u. coal costing $4 per gross ton.]

	Coal-Fired Plants		Blast-Furnace-Gas-Fired Plants	
Fuel Used	Average	Best	Average	Best
Coal or equivalent	$5.592	$4.192	$5.592	$4.192
Producing Labor				
Superintendence	.097	.042	.063	.020
Unloading fuel for immediate use	.073	.020	..	..
Delivery of fuel from general stock	.060	.050	..	..
Coal crushing	.031	.016	..	..
Machine operators—delivering coal	.028	.004	..	..
Firemen	.277	.117	.002	.080
Ash wheelers and conveyor tenders	.182	.068	.001	.038
Water and feed-pump tenders	.175	.084	.169	.056
Boiler washers and cleaners	.092	.026	.182	.068
Attendance, water-purifying plant	.034	.059	.038	.050
All other producing labor	.065	.058	.135	.002
Total producing labor	1.114	.544	.590	.314
Repairs and Maintenance				
Stokers, grates, burners	.208	.109	.053	.010
Boilers and fittings	.235	.065	.268	.046
Boiler settings	.083	.081	.172	.025
Steam mains and pipe covering	.082	.066	.121	.017
All other repairs and maintenance	.397	.225	.188	.056
Total—Labor	.559	.224	.507	.091
Material	.446	.322	.295	.063
Repairs and maintenance	1.005	.546	.802	.154
Miscellaneous Expense				
Tools, lubricants, and miscellaneous	.184	.200	.152	.076
Water	.035	.035	.027	.030
Electric current	.230	.047	.012	.023
Yard switching	.102	.057	.011	.053
Shop expense	.034	.046	.125	.051
Accident and hospital fund	.008	.006	.013	.006
Laboratory expense	..	.004	.018	.030
Total miscellaneous expense	.593	.395	.358	.269
Total boiler-house expense	2.712	1.485	1.750	.737
Grand total cost	$8.304	$5.677	$7.342	$4.929
Boiler efficiency, per cent	60	80	60	80
Coal or equivalent, lb. per boiler hp-month	3133	2350	3133	2350
Price of coal or equivalent per gross ton	$ 4.00	$ 4.00	$ 4.00	$ 4.00

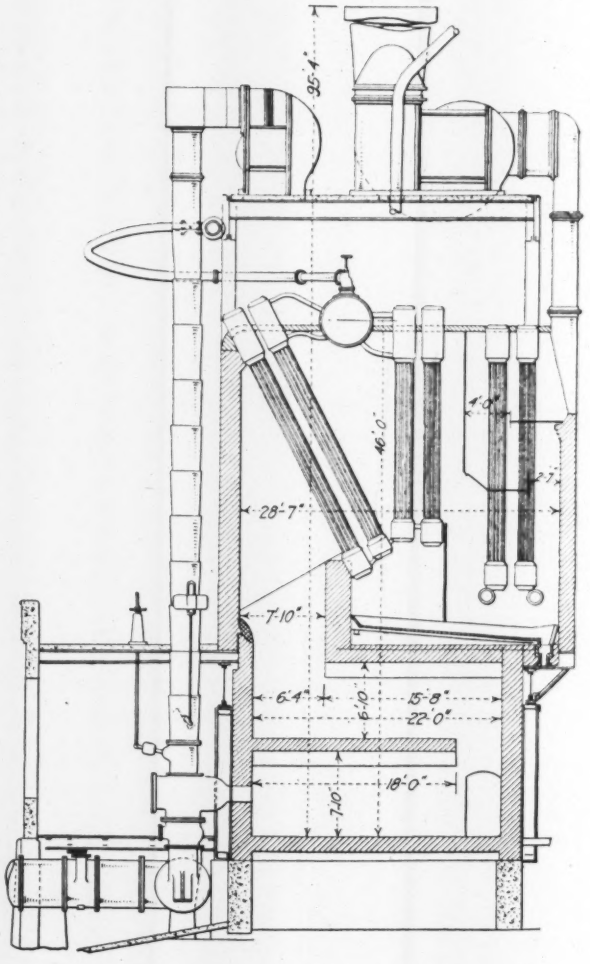

FIG. 3 REPRESENTATIVE BLAST-FURNACE-GAS-FIRED BOILER

Practical Coal Carbonization

A Discussion of High-Temperature and Low-Temperature Carbonization with Special Reference to American Conditions

By F. W. SPERR, JR.,[1] PITTSBURGH, PA.

This paper and another which will be presented under the same title in the July issue are the outgrowth of a request from the Philadelphia Section of The American Society of Mechanical Engineers for an address on the subject of the distillation of coal. It was suggested that the subject be presented in such a way as to show what might or might not be commercially feasible at the present time, and consider especially the standpoint of the power engineer who is constantly being confronted with the question of the better utilization of bituminous coal.

In any such discussion a comparison of low-temperature and high-temperature carbonization is inevitable. The processes of high-temperature carbonization are well established and well known. Much has been claimed for low-temperature carbonization but it has not yet succeeded in establishing itself, and its status and possibilities are by no means so well known.

Low-temperature carbonization offers a very interesting field of possibilities in the way of new processes and new products, but it should be thoroughly realized that no low-temperature process has yet proved commercially successful and that there are serious difficulties, both economic and technical, in the low-temperature carbonization of coking coals—especially under American conditions. In this country, according to the author of the present paper, the best plan of development of coal carbonization would appear to be along the lines of improving the processes of high-temperature carbonization as applied to coking coals, extending the uses of coke and by-products, and directing the application of low-temperature carbonization toward the field of the poorly coking or non-coking coals.

THE carbonization of coal has two practical objects: (1) The production of a solid fuel more useful in form or quality than the original coal; and (2) the recovery of by-products. In the beehive-coke industry we have an example of carbonization conducted for the first object alone, all of the by-products being wasted for the sake of producing metallurgical coke. There is no analogous case of any importance in which the solid fuel is wasted for the sake of the by-products. The gas industry, carbonizing coal for the manufacture of gas, has always obtained considerable value in the coke which it has made as a by-product, and today finds this an asset of continually increasing importance. Modern conditions are such that the two objects—by-products and a more useful solid fuel—must be considered as inseparable.

High- and Low-Temperature Carbonization

In all processes of coal carbonization which have so far attained commercial success, the material is heated to a comparatively high temperature—by which we mean above 800 deg. cent. (1472 deg. fahr.) and usually in the neighborhood of 1000 deg. cent. (1830 deg. fahr.). The apparatus used is the familiar gas retort—horizontal, vertical, or inclined—the gas chamber oven, the beehive oven, or the by-product coke oven. The solid residue is coke, differing in quality according to the apparatus and process used, but always characterized by its well-defined cellular structure and low percentage of volatile matter.

The past fifteen years have seen an enormous amount of work undertaken to develop what is known as low-temperature carbonization. The temperature to which the coal is heated in the different processes is usually between 500 and 600 deg. cent. (about 930 to 1110 deg. fahr.), although in some cases it runs as high as 800 deg. cent. (1472 deg. fahr.). A bewildering variety of apparatus and methods is employed, but the solid residue, which is often appropriately designated as semi-coke, always contains considerable volatile matter (usually about 10 per cent) and in most cases lacks the well-defined cellular structure of coke.

Characteristic Differences Between the Two Processes

The temperature of approximately 800 deg. cent. which marks the dividing line between low-temperature and high-temperature carbonization should not be considered as merely an arbitrary point. There is a distinct difference in the nature of the processes and products of decomposition above and below this temperature. As coal is heated to temperatures below 800 deg., the so-called primary products of decomposition appear. These are characterized by the presence of considerable amounts of paraffin and naphthene hydrocarbons. The tars are thin and of comparatively lower specific gravity, resembling oil instead of ordinary coal tar. Only small amounts of ammonia are produced and the uncondensed gases are small in volume and of high calorific value. At or near 800 deg. cent. a marked change in the character of the products occurs. Secondary decomposition processes begin. The paraffin and naphthene hydrocarbons disappear and the heavy aromatic hydrocarbons, such as naphthalene, anthracene, and similar substances which are absent in the low-temperature tars, are formed in considerable quantities. The density and viscosity of the tars increase. The formation of ammonia largely increases and much greater quantities of gas are produced. The heating value per cubic foot of gas is less, but the total heat units produced in the form of gas are much greater in amount.

Large Expenditures for Low-Temperature-Carbonization Development

Vast sums of money have been expended on various schemes of low-temperature carbonization. A single concern in England has advertised that it has expended over £1,000,000 in research, reminding a contributor to *The Gas World* of the woman who argued that she ought to know how to take care of children, having buried ten. The net result of fifteen years' experimentation by this company and its predecessor was a small plant having a capacity of about thirty-six tons of coal per day which, after functioning for a comparatively short period, has recently suspended operations. In the United States a large amount of money was spent by private parties in the development of the carbocoal process, leading up to the installation of a plant at Clinchfield, Va., financed with Government funds to the extent of $2,750,000 and planned to carbonize 500 tons of coal per day. The history of this plant is best summed up in the words of two of the experts who were actively connected with the enterprise:

> The difficulties encountered at the Clinchfield plant were so numerous and so persistent that, although the plant was kept operating, the manufacturing costs bore no relation to the actual cost of carrying out the steps of the process, and after nearly two years of operation it finally appeared best to shut the plant down temporarily and solve some of the mechanical problems.[1]

The same writers optimistically state that since March, 1922, solutions have been found for several of the most serious difficulties and that it is only a question of solving minor problems now.

What Has Been Accomplished

Besides these two outstanding examples, a long list could be given of other large-scale attempts to commercialize low-temperature carbonization. Government bureaus, universities, and private research laboratories have become interested, and undoubtedly the development of the subject in America, England, and Germany during the past fifteen years has cost many times the amounts that have been cited above. What has been accomplished? Quoting another expert connected with the carbocoal enterprise:

> There have been no developments along low-temperature lines in this country or in England which would justify any assumption that the art has passed from the experimental into the commercial field. Distillation of coal at low temperatures has certainly not been done on a commercial scale—by that is meant a money-making scale, yielding profits sufficient

[1] Chief Chemist, The Koppers Company.

Presented at a meeting of the Philadelphia Local Section of The American Society of Mechanical Engineers, Jan. 22, 1924.

[1] Harry A. Curtis and Earle Daughton, *Chemical and Metallurgical Engineering*, vol. 28 (1923), p. 118.

to carry the operating costs and the capital charges. It has been tried experimentally, on a semi-commercial scale, and in one case on a full-sized commercial plant, but it must be recognized that so far none of these attempts have been successful. The laboratory results remain the most satisfactory of the three phases in their promise of financial returns.[1]

In this connection, high commendation should be given to those associated with the carbocoal enterprise for publishing frank and detailed accounts of their difficulties. We have all too little knowledge of the real results obtained from the many other schemes which have been announced, and unquestionably much money has been and will be wasted in duplicating and reduplicating experiments which are fundamentally unsound.

The distillation of coal is a most fascinating subject and low-temperature carbonization, opening up a field of new engineering problems and new products of little-known composition and unknown possibilities, has come to have a lure to the inventor like that of the North Pole to the explorer. It is to be hoped that, when attained, it may be more useful. It would be altogether wrong to infer from the present lack of success that low-temperature carbonization can never be put on a commercial basis, but the record should be very carefully studied to determine what is its legitimate field and what are the conditions necessary for its practical success.

Recalling the two practical objects of coal carbonization, viz., first, a superior solid fuel, and second, the recovery of by-products, let us compare how these objects are attained by high-temperature and low-temperature carbonization.

Low-Temperature Carbonization in England

With respect to the solid fuel, much misunderstanding is due to reading of British work in low-temperature carbonization without appreciating the great difference between British and American conditions. In England practically all domestic heating is done by means of open grates. After long years of custom the open grate fire has come to be a national institution like afternoon tea, and it is generally agreed that no amount of argument on the grounds of inefficiency, discomfort, uncleanliness, and hard work will be sufficient to uproot the prejudice of the average Englishmen in favor of his open grate fire for many years to come. It is, however, recognized that this institution is largely responsible for the smoke nuisance, under which England suffers more than any other country. There is a well-defined demand for a smokeless fuel suitable for burning in open grates. Gas-works or by-product coke is not altogether satisfactory in this respect, while the low-temperature fuels offer distinct promise. This is the principal objective of most of the British low-temperature carbonization processes, and since, ordinarily, there is no question of competition between low-temperature and high-temperature coke, the two processes must be judged on different grounds.

American Conditions Favorable to Use of Coke

In America, where, happily, coal consumed in open grates is a negligible quantity, the situation is entirely different. Accustomed to the use of anthracite, people are readily turning from this to coke, millions of tons of which are being sold annually for domestic purposes. Even in places where soft coal is largely burned there is a growing appreciation of the superiority of coke, even at considerably higher prices. The production of clean, high-grade, smokeless fuel is coming to be recognized not so much as a burden as one of the civic duties of the gas manufacturer. A very large proportion of new gas-works capacity installed in many cities during the past few years has been in the form of by-product coke ovens, the manufacture of high-grade coke for domestic purposes being an important consideration in the selection of the type of plant.

Comparison of Application to Coking Coals

American conditions require that comparison between low-temperature and high-temperature carbonization be made primarily with respect to their application to coals which are suitable for the manufacture of coke in the by-product coke oven. It is believed that this comparison will show that it is difficult for low-temperature carbonization to compete economically with the by-product coke oven in the treatment of coking coals, and that the natural field of the former would rather appear to be in the treatment of the poorly coking or non-coking coals. The districts of America in which low-temperature carbonization might find such a field would be those in which the poorly coking coals are available at prices considerably lower than the coking coals.

Considering low-temperature carbonization under conditions where it must treat coking coal and meet competition with high-temperature carbonization, there is no necessity for entering upon any argument as to the relative merits of the solid fuels produced by the two processes. The marketing of low-temperature coke is as much of an experiment as its production and its value must be considered speculative, but we may, for purposes of comparison, assume that the two will be sold at the same price.

Value of By-Products

The value of the by-products must now be considered. Table 1 shows a comparison of the yields of by-products from the two processes, assuming the use of a high-grade "gas coal" of about 34 to 35 per cent volatile matter. The yields given for the by-product coke oven are those which are regularly obtained with modern oven operating on 100 per cent high-volatile coal. There are many conflicting claims as to yields to be expected from low-temperature carbonization, but the more optimistic figures which are often published must stand the test of long-continued, large-scale operation before they can be accepted. Some statements give credits for the production of creosote oil, lubricating oils and greases, pitch, etc. These would require supplementing the usual organization of a carbonization plant with that of a tar-distillation plant, and for a fair comparison we should have to do the same in the case of the by-product coke plant and show credits for phenol, cresylic acid, creosote oil, naphthalene, anthracene, and other products. Since it is our purpose to compare two carbonization processes with respect to their usual primary products, the operation of a tar-distillation plant does not enter into the problem.

TABLE 1 COMPARATIVE YIELDS OF BY-PRODUCTS FROM THE BY-PRODUCT COKE-OVEN AND LOW-TEMPERATURE CARBONIZATION PROCESSES

	By-product coke ovens	Low-temperature carbonization
Gas (550 B.t.u.), cu. ft.	11,500	6,000
Tar,[1] gal.	12	20
Motor fuel, gal.	2.6	2.6
Ammonium sulphate, lb.	25	10

[1] With the improvement of the by-product coke oven, the yield of tar has steadily increased. Recently built ovens using Pittsburgh coal are producing from 13 to 14 gal. per ton.

The direct yield of gas from low-temperature carbonization is less than that given in Table 1, but the heating value is higher and the figures are put on the same basis as regards heating value for purposes of comparison. It will be seen that the high-temperature process has a great advantage with respect to gas and ammonium sulphate. The present tendency in high-temperature carbonization is to release the entire production of high-grade gas by using producer gas for heating the ovens, and in order to put the comparison on an equal basis it is assumed that the low-temperature plant would be heated in the same way Assuming the credit for the gas to be as low as 30 cents per 1000 cu. ft., and assuming tar to be sold at 5 cents per gal., we have the values given in Table 2.

TABLE 2 VALUES OF BY-PRODUCTS FROM THE COKE-OVEN AND LOW-TEMPERATURE CARBONIZATION PROCESSES

	By-product coke ovens	Low-temperature carbonization
Gas at 30 cents per 1000 cu. ft.	$3.45	$1.80
Tar at 5 cents per gal.	0.60	1.00
Motor fuel at 20 cents per gal.	0.52	0.52
Ammonium sulphate at 3 cents per lb.	0.75	0.30
	$5.32	$3.62

Under these conditions low-temperature carbonization is at a serious disadvantage in comparison with the by-product coke oven. Those who are looking for increased conservation of our resources in nitrogenous fertilizer will be disappointed because the amount of ammonium sulphate produced is much less than in the by-product coke oven. Tar is the principal by-product recovered in low-temperature carbonization and it is argued that the quality of this tar is such that it should have a higher value than by-product-coke-oven tar. The figures in Table 2 show that with gas at 30

[1] Charles V. McIntire, Report of the Low-Temperature-Carbonization Section, Carbonization Committee, American Gas Association, 1923 Convention.

cents per 1000 cu. ft., low-temperature tar would have to command nearly three times the price of high-temperature tar in order that the total value of the by-products might equal the value of those obtained by high-temperature carbonization.

LOW-TEMPERATURE TAR

The tar obtained in low-temperature carbonization differs radically in character from ordinary coal tar. Low-temperature tars "are thin and light, having a consistency much more resembling oils. They have a specific gravity so nearly approaching unity that the separation of water from the oil is difficult."[1] Much less is known about the chemical composition of low-temperature tar than about that of ordinary coal tar. Generally speaking, it may be stated that the low-temperature tar contains more phenols (tar acids), more neutral oils (naphthene and paraffins), and less solid aromatic hydrocarbons (e.g., naphthalene, anthracene, etc.) than high-temperature tar. The neutral hydrocarbons in low temperature tar have a remarkable similarity to ordinary kerosene.[2] It is commonly supposed that low-temperature tar contains a much higher percentage of low-boiling constituents and a lower percentage of pitch than coke-oven tar, but the investigations of Morgan and Soule[2] indicate that such is not necessarily the case. Tar made from Pittsburgh coal in the primary retort of the carbocoal process had a distillation curve remarkably similar to that of coke-oven tar and the percentage of pitch was nearly the same, although the pitch from low-temperature tar was softer, lighter, contained much less free carbon, and melted at a lower temperature. Low-temperature tar itself contains considerably less free carbon than high-temperature tar.

REQUIREMENTS OF THE CREOSOTING INDUSTRY

The great commercial outlet for coal tar is in the wood-creosoting industry. Outside of this industry, there is no important field[3] which is now known in which low-temperature tar would have any special advantage that would warrant a higher price for it than for high-temperature tar. Under present conditions the price of coal tar is really on a fuel-oil basis, and millions of gallons are being used annually in the manufacture of open-hearth steel.

Considering the demands of the wood-creosoting industry, we find that neither low-temperature tar nor the oils distilled therefrom can meet the present creosoters' specifications. The high percentage of tar acids and the low free carbon would appear advantageous, but the neutral oils and low specific gravity are drawbacks. The principal point of difficulty in present specifications is the specific gravity—low-temperature tars and distillates being too light to meet these specifications. Proposals are being made to change the specific-gravity specifications so that low-temperature tars and oils can be admitted, but this would necessitate a specification for neutral oils and another obstacle would be encountered. Creosoters object very strongly to the presence of even small amounts of paraffin hydrocarbons in their oils and it would be logical to expect them to object very strenuously to a distillate containing nearly 14 per cent of kerosene and which would appear to be practically the same as a solution of tar acids in crude petroleum.[4]

Above all such considerations is the outstanding fact that we know nothing as to the actual practical value of low-temperature tar or its distillates as wood preservatives. Many years of uphill work are ahead of any low-temperature-carbonization proposition before it can even place its material on the same basis as high-temperature tar. The carbocoal plant at Clinchfield found that the marketing of the tars "was not an easy matter."[5] Unless conditions in America undergo a marked change, there is no reason to believe that low-temperature tar can be marketed at any considerably higher price than tar made in the modern by-product coke oven. Here again conditions in Europe are different. There the high prices of petroleum and petroleum products make the production of low-temperature tar a more attractive proposition.

BASIS OF COMPARISON OF HIGH-TEMPERATURE AND LOW-TEMPERATURE CARBONIZATION

Summing up the situation with respect to the value of the products obtained, we may state:

1 The solid residue from low-temperature carbonization must be sold at or below the price of by-product coke
2 The price of low-temperature tar must be the same as or only slightly higher than that of high-temperature tar
3 The prices of the other primary products—gas, ammonium sulphate, and motor fuel—will be the same in both cases.

With gas and tar at normal prices, the value of the by-products from low-temperature carbonization is considerably less than the value obtained from high-temperature carbonization. The yield of solid residue is, however, greater in the low-temperature process. Assuming that both types of plant are heated with producer gas made from the carbonized fuel, it is believed that net yields of 58 per cent of coke from the high-temperature process and 66 per cent from the low-temperature process would represent a fair comparison in carbonizing high-grade gas coal.

Let C = price of coal in dollars per net ton
G = price of gas in dollars per 1000 cu. ft.
X = price of coke in dollars per net ton
F = sum of operating expenses, fixed charges and profits.

Then, for high-temperature operation

$$0.58X + 11.5G + 1.87 = F + C$$

For low-temperature operation, assuming the tar to be sold at the same price as high-temperature tar, viz., 5 cents per gal.,

$$0.66X + 6G + 1.82 = F + C$$

RELATION BETWEEN PRICES OF COAL AND GAS

Suppose we assume in the first place that the sum of operating expenses, fixed charges, and profits is the same in both cases. Since the price of coal is also the same,

$$0.58X + 11.5G + 1.87 = 0.66X + 6G + 1.82$$

and

$$X = \frac{5.5G + 0.05}{0.08}$$

If the low-temperature tar can be sold for 8 cents per gal., $X = (5.5G - 0.55)/0.08$. These relations are shown in Fig. 1. The curves show the price at which coke must be sold by the low-temperature plant in order that it may earn the same fixed charges, operating expenses, and profits as a by-product coke plant receiving any given price for gas. For example, if gas is worth 30 cents per 1000 cu. ft. and low-temperature tar 5 cents per gal., conditions must be such that coke can be sold at as high as $21 per ton before the low-temperature plant can earn the same amount as the high-temperature process. This is irrespective of the price of coal.

CONVERSION AND FIXED CHARGES

For the high-temperature carbonization of coking coals, the by-product coke oven is the most economical investment. There are certain very difficult engineering problems which must be overcome in low-temperature carbonization before it can be made equally economical.

Assuming gas to be worth 30 cents per 1000 cu. ft., we can show what must be the sum of conversion and fixed charges in each case in order to be able to sell coke at the same price as coal. The relations are shown in Fig. 2. With coal at $5 per ton the high-temperature process has a margin of about $3.25 per ton of coal to cover conversion and fixed charges, while the low-temperature process, selling tar at 8 cents per gal., has a margin of only $2.50. If the low-temperature tar is sold at 5 cents per gal., the margin

[1] S. W. Parr and T. E. Layng, *Journal of Industrial and Engineering Chemistry*, vol. 12 (1921), p. 14.

[2] J. J. Morgan and R. P. Soule, *Chemical and Metallurgical Engineering*, vol. 26 (1922), p. 923.

[3] Metallurgical flotation is a possible exception, but the quantities used in this industry are not sufficiently large to affect the argument.

[4] The low-temperature tar distillate "upon removal of the phenols resembles crude petroleum in properties and uses." Morgan and Soule, *ibid.*

[5] Charles V. McIntire, Report of the Low-Temperature Carbonization Section, Carbonization Committee, American Gas Association, 1923 Convention.

is only $1.90. Thus, low-temperature carbonization must overcome a handicap of from $0.75 to $1.35 per ton, which would be increased $0.55 for each rise of 10 cents in the price of gas.

Coal Carbonization and Power Reduction

The author has been requested to discuss especially the subject of the carbonization of coal in connection with power production. It is well recognized that the burning of raw coal in any form involves an economic waste in the loss of by-products which could be recovered by preliminary carbonization. The smoke nuisance due to the burning of raw coal also involves a direct annual waste of millions of dollars, not to speak of the loss in health and comfort

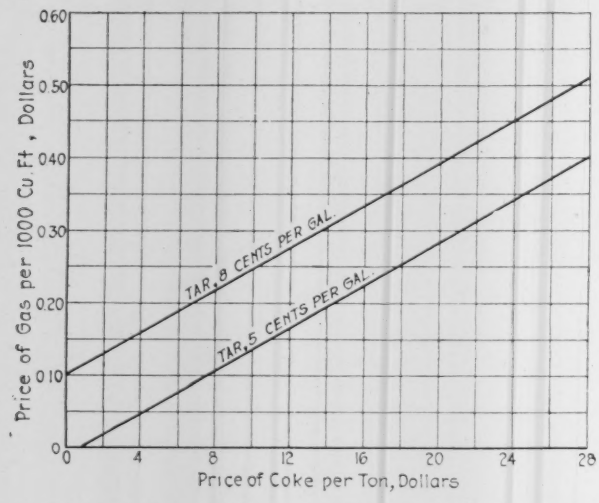

FIG. 1 RELATION BETWEEN PRICE OF GAS AND COKE NECESSARY FOR LOW-TEMPERATURE CARBONIZATION TO EARN SAME EXPENSES AND PROFITS AS HIGH-TEMPERATURE CARBONIZATION

which cannot be measured in money. It is estimated that the electric utilities consume over 35,000,000 tons of bituminous coal per year and that nearly 200,000,000 per year are consumed as industrial fuel, not including what is used by mines, coke ovens, and public utilities. All of this is being burned without the recovery of by-products.

The possibility of the treatment of bituminous coal used at large power stations in such a way as to recover the by-products and produce a smokeless fuel has attracted much attention and interest, but has seen very little practical development. In this country neither high-temperature nor low-temperature carbonization has passed the experimental stage in direct application to power production. Coke breeze is being largely used as a boiler fuel, but is principally consumed in the by-product coke plant where it is produced and very little of the large sizes of coke is utilized for steam raising. A large-scale experiment in low-temperature carbonization, applied to power production, is being made by Henry Ford. In this it is proposed to burn the carbonized residue in a large power plant. This proposition is not yet in operation and much time must elapse before judgment can be passed on the results obtained.

In England considerable amounts of coke are used as boiler fuel, but there is no case in which a coke plant has been built primarily for the sake of manufacturing coke for power production. There have been a number of proposals for the application of low-temperature carbonization in this connection, but there is no reason to believe that any of these have passed the experimental stage. Any discussion in this connection must therefore be largely speculative. We have no knowledge from any source whatever as to practical results obtained with the residue from low-temperature carbonization.

Coke as Boiler Fuel

A book on Coke and Its Uses in Relation to Smoke Prevention and Fuel Economy, recently published by E. W. L. Nicol, of London, contains interesting information on results obtained in British practice with coke as a boiler fuel. In the larger plants employing chain-grate stokers, coke is principally used in conjunction with coal—the system recommended being one in which a layer of coke from 6 to 7 in. thick is fed between two layers of coal, each about two inches in thickness. Very satisfactory results are claimed for this system, the figures published showing decided advantage over the use of coal alone. The size of coke employed is about $\frac{1}{2}$-in. to 1-in. Coke breeze is used on the chain-grate stokers without coal as is done in America.

In hand-fired boilers very satisfactory results are obtained with coke of from 1 to $1\frac{1}{2}$ in. without the addition of coal. It is claimed that the overall thermal efficiency obtained is well above the average realized with coal-fired boilers.

Illingworth[1] describes the use of coke mixed with a little coal as giving better efficiency than coal alone, and states that the same boilers have been operating on coke for twelve or fourteen years.

Semi-Coke for Power Production

In application to power production, some of the difficulties of low-temperature carbonization disappear. Dry semi-coke is prone to spontaneous ignition and cannot be safely stored unless subjected to some secondary treatment such as briquetting. However, if the operations can be adjusted so that the semi-coke can be consumed as fast as it is made, this storage problem would be

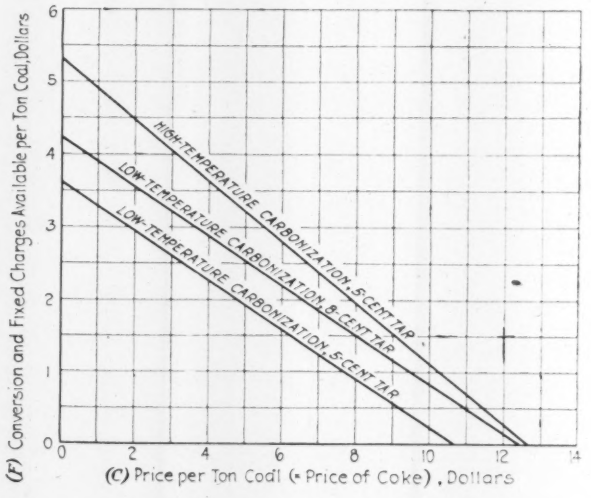

FIG. 2 RELATION BETWEEN *F* AND *C* WHEN COKE IS TO BE SOLD AT SAME PRICE AS COAL

(*F* = amount available for conversion and fixed changes per ton of coal; *C* = price of coal (= price of coke) per ton; gas at 30 cents per 1000 cu. ft. The difference between the earnings of high-temperature and low-temperature carbonization processes is increased 55 cents per ton for each rise of 10 cents in the price of gas.)

avoided. The physical form of the semi-coke is not such a handicap as in other applications and there is no necessity for briquetting or for otherwise complicating and increasing the expense of the process for the sake of making a fuel salable in competition with coal and coke. It may be possible to employ the semi-coke in pulverized form, although the comparative costs and efficiencies in this connection have not been thoroughly worked out.

Starting with a coal of 14,000 B.t.u. per lb., the heating value of the coke produced is about 13,200 B.t.u. per lb. and that of the semi-coke is about the same. It will be assumed for purposes of comparison that each is equivalent to coal on a heating-value basis, i.e., that 1.06 lb. of coke or semi-coke, furnishing 14,000 B.t.u., are equivalent to 1 lb. of coal.

Comparison with Respect to Power Production

Let us consider a power plant consuming 1000 tons of coal per day and the conditions that would result from the installation of a carbonization plant supplying the fuel necessary to produce the same amount of power. The approximate daily power production in a plant consuming 1000 tons of coal per day would be 1,457,000 kw-hr. with turbo-generators of the condensing type and assuming a boiler efficiency of 78 per cent. The following are data necessary for the subsequent calculations.

[1] Proceedings of the South Wales Institute of Engineers, July 20, 1922.

Heating value of coke	13,200 B.t.u. per lb.
Heating value of low-temperature residue	13,200 B.t.u. per lb.
Heating value of coal	14,000 B.t.u. per lb.
B.t.u. per kilowatt	19,215
Coke or low-temperature residue required to produce the same number of kw-hr. as 1000 tons coal	1060 tons per day

It is assumed that both the high-temperature plant and the low-temperature plant are heated with producer gas. The gas producers, if equipped with waste-heat boilers and steam-raising water jackets, produce a large proportion of the steam required for the operation of the plant. However, some extra power must be purchased and it is assumed that this will be obtained from the power plant. Making allowance for this, it is estimated that in order to produce the 1060 tons of coke required for the same power production as the original coal-fired plant, the high-temperature process would require 1900 net tons and the low-temperature process 1660 net tons of coal per day.

In order that either coke or low-temperature residue can be used to replace raw coal, sufficient income must be derived from the sale of by-products to pay for the capital charges and cost of operation of the carbonization plant and to pay for the extra coal required. Any additional revenue may be applied so as to decrease the cost of power.

Relation to Price of Gas

The comparisons naturally result in conclusions similar to those which have already been drawn. The proposition is practically the same as that of undertaking to sell coke for the same price as raw coal. Its success will generally depend upon the possibility of selling gas at a sufficiently high price. If the investment and operating charges are the same in each case, the low-temperature process must sell its gas considerably higher than the high-temperature process. The combined operating cost and fixed charges must be much lower in the case of the low-temperature process and the handicap which must be overcome is considerable. The relations are shown in Fig. 3, which differs from Fig. 2 in that credit is now allowed for coke only at the equivalent cost of coal required for producing the same amount of power. This credit is less than that based on an equal price per ton, in proportion as the heating value of the coke is less than that of the coal.

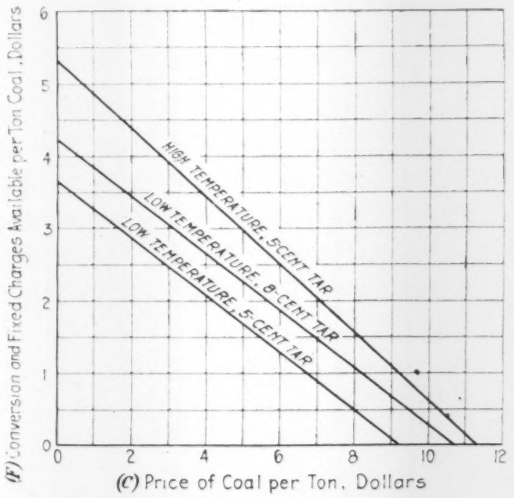

FIG. 3 RELATION BETWEEN F AND C WHEN CREDIT IS ALLOWED FOR COKE AT EQUIVALENT COST OF COAL FOR PRODUCING SAME AMOUNT OF POWER

(F = amount available for conversion and fixed charges per ton of coal carbonized; C = price of coal per ton; price of gas = 30 cents per 1000 cu. ft.)

The hope has been expressed that the returns from the sale of by-products will not only cover operating expenses and fixed charges, but that there will be a sufficient surplus so that the cost of power can be reduced. The best possibility in this direction would appear to lie in obtaining a higher price for gas. Take the case of the plant burning 1000 tons of coal per day. With coal at $5 per ton, the fuel cost is $0.00344 per kw-hr. With the high temperature process operating in conjunction with such a plant, each 10-cent increase in the price of gas above the base price necessary to meet the necessary expenses and charges will reduce the fuel cost $0.00157 per kw-hr. or nearly 45 per cent. Each 10-cent increase in the price of gas from low-temperature carbonization would reduce the fuel cost $0.00072 or about 20 per cent. The relations are shown in Fig. 4.

It might be argued that the same consideration would apply to an increase in the price of tar from the low-temperature process, but there is by no means such flexibility in this respect as in the case of gas, and a difference of 2 cents per 1000 cu. ft. for gas from the high-temperature process would have more effect than a difference of 1 cent per gal. in the price of tar.

Proper Field for Low-Temperature Carbonization

Studies of the foregoing character indicate that any low-temperature process for the carbonization of coking coals is severely handicapped by economic considerations. The best promise of any such process would appear to lie in connection with power production where it can operate at minimum cost and where the physical quality of the semi-coke is of minor importance. Here, however, it must meet competition with high-temperature coke—which has been little investigated in this connection and which offers considerable promise of successful application. If high-temperature coke can be burned with a reasonable degree of efficiency for power production, the low-temperature product must overcome a considerable cost margin before it can compete economically.

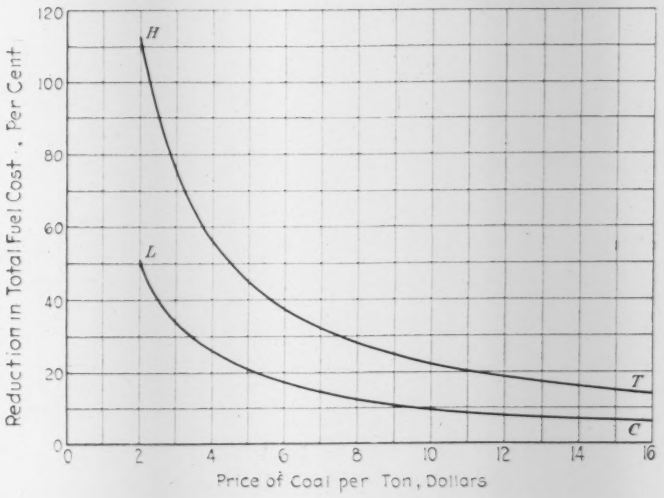

FIG. 4 PERCENTAGE REDUCTION IN FUEL COST OF POWER

(For an increase in price of gas of 10 cents per 1000 cu. ft. over base price necessary to meet fixed charges and operating expenses.)

Furthermore, it is in the treatment of coking coals that low-temperature carbonization also finds most of its technical difficulties. These will be described in another paper which has been prepared by A. R. Powell. They include such troubles as sticking of material in the retort due to accumulation of tarry matter and expansion; building up of hard coke on the heating surface to such an extent that heating is retarded and the mechanism broken; increased wear and tear; and impossibility of applying the principle of internal heating by hot gases. These are much diminished when treating poorly coking or non-coking coals. Some processes even contemplate destroying the coking properties of high-grade coals by oxidation preliminary to low-temperature carbonization.

On the other hand, as coals become poorer in coking quality, a point is reached where it becomes difficult or impossible to use the horizontal coke oven. It would seem that the proper field for low-temperature carbonization is in the treatment of coals which cannot thus be coked. Here, however, it must face two other possibilities. The first is the high-temperature vertical retort or oven which is continually being improved in economy and efficiency. The second is the development of means for making good coke out of coals which have hitherto been classed as poorly coking or non-coking. Much progress is being made in this direction and even at the present time large quantities of coke are being regularly made from coals which ten years ago were believed incapable of satisfactory treatment in the by-product coke oven.

Inclusions in Steel

THE mechanical engineer as a rule does not receive sufficient information as to the character of the steel with which he has to deal, a fact which not infrequently leads to undesirable consequences.

This applies not only to castings but to rolled products, and, for example, in making an expensive die from a piece of steel it happens quite often that after a large amount of money and time has been spent it is discovered that the steel is so "dirty" that it is not suitable for the given purpose.

As a general rule steel specifications contain information as to the contents of carbon and other constituents in the metal, but do not carry any information in regard to the specific characteristics of the particular piece of steel with which the engineer has to work.

Inclusions in steel may be roughly divided into so-called slag inclusions, inclusions of metallic oxides, and sulphide inclusions. Opinions as to the effect which inclusions of manganese sulphide and silicate produce on the mechanical properties of steel differ, but many cases of failure in service have been known which were traceable to the influence of these inclusions. These inclusions are particularly harmful in steel which is to be subjected to quenching operations, as hardening characteristics frequently start from the larger inclusions.

There are several simple methods by which the presence of sulphide and phosphide inclusions can be discovered. These are the so-called contact processes based on the fact that when acted upon by an acid, the sulphides and phosphides of iron decompose with the local evolution of hydrogen sulphide and hydrogen phosphide which may be made to discolor a surface suitably sensitized.

There are two main processes of the so-called sulphur printing—the older method developed by Heyn and Bauer, and the more recent Baumann process. The second of these two requires less manipulative ability and can be more easily performed. The following description as to these two processes has been taken from An Introduction to the Study of Metallography and Macrography by Leon Guillet and Albert Portevin, translated by Leonard Taverner, London, G. Bell & Sons, Ltd., 1922.

Heyn and Bauer's Process. On the polished surface is placed a piece of silk which is impregnated with the following solution by means of a brush or wad of cotton wool:

Mercury bichloride	10 grams
Hydrochloric acid (sp. gr., 1.124)	20 cc.
Distilled water	100 cc.

The evolution of H_2S forms a black precipitate of sulphide of mercury, adhering to the silk at the points corresponding to sulphide inclusions. As a general rule the operation requires four or five minutes. Large evolutions of H_2S form bubbles under the surface of the thin silk, but these may be made to disappear by touching them lightly with a brush impregnated with fresh solution. It is essential that the silk shall adhere perfectly to the specimen throughout the experiment; also, from time to time, it is necessary to replace the used solution with fresh solution by painting over the surfaces with the brush. Finally, the silk is removed and carefully washed with water to remove all traces of acid without removing the black precipitate. The silk furnishes an exact image of the areas rich in sulphide inclusions, and if the sulphide inclusions are regularly distributed through the material, the silk will be of a uniform pale-gray color, without any marked points of contrast.

The areas rich in phosphorus evolve phosphureted hydrogen, which forms a lemon-yellow precipitate of mercury phosphide; therefore these are distinct from the sulphide spots, which are black. The evolution of phosphide is very slight compared to the evolution of H_2S, which is extremely rapid.

Baumann's Process. Bromide paper is wetted by immersion in dilute sulphuric acid (3 per cent) and the sensitized surface is then brought into contact with the polished surface of the specimen to be examined, movement of the paper and the presence of air bubbles being avoided. The paper is left in contact for some definite period (20 sec. to 5 min.), and on its removal there is found an image of varying intensity outlining the sulphide or phosphide of silver. If further proof is needed, it is necessary to remove the attacked surface with a file or by other suitable means before repeating the experiment.

Bibliography on Mechanical Instruments Available

THE American Society of Mechanical Engineers has available for loan a few manuscript copies of a bibliography on Measuring Instruments, prepared particularly from the viewpoint of the mechanical engineer by F. J. Schlink, member of the Special Research Committee on Permanency and Accuracy of Indication of Engineering Instruments.

This bibliography, which was prepared during a number of years of close specialization in metrology, particularly in the use of physical methods in engineering measurements, seeks to cover only those fields which are not adequately taken care of in other reference sources. Flow meters and aeronautic instruments, for example, being already covered by printed bibliographies, are not included in the one here referred to.

The bibliographic entries, about 200 in number, will be found classed under the following headings:

1 General Material, Theoretical or Basic, on Physical and Mechanical Instruments.
2 Measurement and Production of Small Linear and Angular Displacements and Distances.
3 Theory and Measurement of Vibrations, Measurement of Speeds and Time Intervals.
4 Frictional and Other Types of Hysteresis and Their Relation to Instrument Design and Testing; Accuracy, Sensitivity, and Variance.
5 Dynamometers, Measurement of Force (except weighing scales), Torque and Accelerations.
6 Measurement and Control of Temperature and Humidity.
7 Weighing Scales.
8 Pressure Gages, Manometers, Aneroid Barometers.
9 Engine Indicators.
10 Properties and Design of Springs.
11 Miscellaneous Instruments.

A list of other bibliographic source material specially useful in the field of measurement and measuring instruments is appended.

Valuable Report on Plumbing Installations

THE Department of Commerce, Herbert Hoover, secretary, has just announced the completion of its report on Recommended Minimum Requirements for Plumbing Installations in Dwellings and Similar Buildings. This report is the second in a series of which Recommended Minimum Requirements for Dwelling Construction was the first. It is the result of two years' work of a committee of distinguished sanitary engineers, headed by Prof. George C. Whipple, of Harvard University, and presents their final judgment on many disputed questions in the plumbing industry. This committee is allied with that on building codes of which Dr. Ira H. Woolson is chairman.

In addition to a code of minimum requirements recommended for state and municipal adoption, the report gives detailed results of extensive experiments at the Bureau of Standards with complete plumbing installations. It discusses public inspection of plumbing work, the desirability of licensing plumbers, and the relation of plumbing to health. The report takes up water supply as related to plumbing, and gives methods of predicting loads on plumbing systems. The latest discoveries regarding corrosion of metals are explained in the Appendix and results are given of experiments on the diffusion of gases in pipes.

The report gives directions for design of plumbing which materially reduce cost as compared to present practice, without loss of efficiency; and the recommended code is drafted to permit utilization of this information wherever cities may wish to take advantage of it. Much of the information applies to building of large size as well as to dwellings.

Copies of this report may be obtained by addressing the Superintendent of Documents, Government Printing Office, Washington, D. C. It contains 250 pages of text and over 100 illustrations. The price is 35 cents.

Analysis of a Machine-Shop Problem on a Quantity and Final-Economy Basis

By A. L. DE LEEUW,[1] NEW YORK, N. Y.

This paper discusses the nature of the analysis which should be followed in determining the most economical method of machining work, either in large or small quantities. It leaves out of consideration all items excepting those relating to the actual machining processes. Particular attention is called to the difference between the saving of labor cost and the ultimate economy. As an example some of the operations on an automobile connecting rod are taken.

THE best machine-shop methods are those which give the highest ultimate economy under the existing conditions. This statement of an obvious truth is made here at the beginning in order to call particular attention to the fact that it is the ultimate economy which counts and not the economy of a single operation, and that some method or methods may be good under one set of conditions and bad, or at least less desirable, under another.

This paper deals with the problem of analyzing machine-shop operations with an eye on the ultimate economy. However, no factors will be considered which do not bear directly on the machining operations. Such items as handling facilities, routing systems, systems of wage payment, etc., will be ignored. They contribute to the ultimate economy of the shop but not to that of the machining methods.

Determining Unit Cost of a Single Operation

In order to approach the subject gradually, consideration will be given first to the simplest possible problem, namely, one operation only on only one kind of piece.

Let n = number of pieces produced per hour
w = wages per hour
N = number of hours per year during which this operation is performed
V = cost of machine, floor space, and permanent equipment
p = percentage charged for interest and depreciation
f = factor (action) denoting that part of the time the machine is usefully employed.

Then fnN is the number of pieces produced per year at a direct labor cost of wN, and pV is the overhead directly chargeable to the machine. The unit cost is then

$$\frac{pV + wN}{fnN}$$

As unit cost is proportionally connected to f and n, these factors may be omitted in further analysis. However, they must be considered when computing actual cost.

The formula now becomes:

$$\text{Unit cost is proportional to } \frac{pV}{N} + w$$

in which the first term is the machine cost and the second the wage cost. It should be noted here that the machine cost is figured for the number of hours the machine is operating and not for the number of hours it is standing in the shop. This is important when special machinery is introduced.

As an example, taking V = \$8000, N = 2400, p = 15 per cent = 0.15, and w = \$0.75, $(pV/N) + w$ = \$1.25. This \$1.25 is the cost of the operation done when the operator can produce n pieces per hour, and when he and the machine can be kept busy the fraction f of the total time. For instance, if the operator works at the rate of 100 pieces per hour but can keep busy only 80 per cent of the time, the unit cost will be $125/(0.80 \times 100) = 1.5625$ cents.

Additional Factors Entering into the Complete Formula for Unit Cost

Certain factors did not appear in the general formula and may be left out for a first approximation. These factors will now be considered.

Tool Expense. In the first place, there is the tool expense. This consists of two items, first cost and cost of maintenance—sharpening. Where a certain tool is used constantly for one operation only, these two items can be calculated, and should be if the tool or its maintenance is expensive. The unit cost C_u is then

$$C_u = \frac{pV + wN}{fnN} + t_u$$

in which t_u is the unit tool cost.

Cost of Power. Another item which might be considered is the cost of power. However, power is required whatever machine is used to remove the metal and is in almost all cases a small item. If considered at all, it is to be borne in mind that the power cost is also independent of the factors appearing in the original formula and is merely added to the cost indicated by it.

Set-Up Time. This item modifies the factor f. If this factor is 0.8 during the time the machine operates, then the actual factor to be used is less than 0.8 and becomes so by the fact that machine and operator were non-productively employed during the time required for setting-up. It will be seen, then, that f is variable and depends on the length of the job. This matter is of importance when the job is of short duration; it is of small importance for long jobs and vanishes when a machine is constantly employed on the same work.

For the rest, the factor f takes care of a number of items such as tool renewal, temporary absence of the worker, etc. In factories where each machine is assigned to a certain job, the factor f should be determined and should be carried on the record as a constant.

The value of the unit cost as expressed by the formula and its additions can be used to compare the economy of various methods of performing a single operation.

Comparison of the Economy of Various Methods of Performing a Single Operation

The examples of comparative analysis given in this paper all refer to machining operations on the automobile connecting rod shown in Fig. 1. This piece requires various operations of drilling, reaming or broaching, spot facing, chamfering, tapping, milling, and sawing.

As first example the simple operation of sawing the slot at the small end of the connecting rod will be taken. Three cases will be considered: namely, (*a*) when the quantity is 100, (*b*) when it is 10,000, and (*c*) when it is unlimited.

In the first case a machine already available must be selected, the quantity being too small to justify consideration of a machine more especially adapted to the work. In this case almost any milling machine will do.

In all milling operations the cutter should be as small in diameter as possible, consistent with the requirements of the work and with proper size of arbor. Assuming the arbor to be 1 in. in diameter or about $1^1/_2$ in. over the arbor collars, the size of the cutter must be $1^1/_2$ in. + 2 × depth of cut = $1^{11}/_{16}$ in. To allow for the proper amount of penetration when the vertical feed is used, and for the fact that a standard-size cutter is desirable, a 2-in. cutter will be selected. The question remains now which feed to select.

Using the table feed requires a cutter traverse of $^3/_4$ in. plus the approach, which in this case is about $^1/_2$ in. The total length

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[1] Consulting Engineer. Mem. A.S.M.E.

Contributed by the Machine Shop Division and presented at the Spring Meeting, Cleveland, Ohio, May 26 to 29, 1924, of The American Society of Mechanical Engineers. Abridged. All papers are subject to revision.

to be milled is therefore $1^1/_4$ in. If the vertical feed is used the length to be milled is equal to the depth of the slot plus the offset in a 2-in. circle when the chord is $^3/_4$ in. This is less than $^1/_{16}$ in., so that the distance to be traversed by the cutter is $^{19}/_{32}$ in. or, say, $^5/_8$ in. We therefore select the vertical feed.

Ignoring tool cost and power cost, the method of calculating is as follows (certain figures being assumed for obvious reasons):

Speed of cut	70 ft. per min. (135 r.p.m.)
Feed per revolution	0.030 in.
Feed per minute	4.05 in.
Time for cut	10 sec.
Time for chucking	15 sec.
Time for returning table	5 sec.
Total time	30 sec.
Time for 100 pieces	50 min.
Time for set-up	25 min.
Total time	75 min.
Value of machines and floor space	$2000
pV = $300 per year	= $0.125 per hr.
w = wages	= 0.75 per hr.
Total per hr.	= $0.875
Total cost of job	$1.095
Unit cost	1.095 cents

Modification of Method Described where Large Quantities Are Involved

The question now is, to what extent, if at all, should this method be modified if the quantity is 10,000 (in one lot and no other lots expected)?

The total time for milling and set-up would be $(100 \times 50) + 25 = 5025$ min. As the cost per hour would be again $87^1/_2$ cents, the total cost of this job would be $73.28. This amount is not enough to try to reduce it by a special fixture, for, whatever means of chucking may be provided, there will always remain the milling and set-up times which will amount to more than one-third of the total time, so that less than two-thirds of $73.28 can be saved.

If, however, the job should be recurrent, say, once a year, a special fixture might be considered provided there were a fair certainty that the job would last a number of years.

An entirely different problem is presented when the quantity is unlimited or practically so. In this case savings are calculated not on a given quantity but on a year's production.

The productive part of the operation is the sawing. Chucking and manipulation of the machine are necessary but not productive as they interrupt the essential part of the operation, the cutting. As the cutting time is 10 sec. and the total time per piece 30 sec., it follows that the production could be tripled if the non-productive elements could be eliminated or if they could coincide with the cutting. This means that one piece must be cut while another is being chucked. The most perfect arrangement for obtaining this result is one by means of which the operation becomes continuous, such, for instance, as a rotating fixture, and any such device reaches its highest possible efficiency only when both operator and machine work all of the time.

Testing the case under consideration by this principle and assuming the amount of time for chucking and cutting to be correct as given before, it is found that:

In order to cut continuously the feed must be in the direction of the axis of the small hole and not toward the center as heretofore.

The shape of the fixture to adopt will be that of a hollow cone, with the pieces of work chucked on the inside, so that that part of the connecting rod on which the work is done shall lie at the small diameter of the cone. The fact that the other end of the connecting rod is wider necessitates this arrangement.

With such a fixture it will be possible to double up, using two hollow cones joined at their small diameter.

As a large part of the fixture is relatively far removed from the cutter, it will be possible to chuck two pieces with one manipulation of the clamping bolts, so that it should be possible to chuck two pieces in 20 sec. instead of one piece in 15 sec.

The following conditions now obtain: Two pieces are chucked in 20 sec. and two pieces are cut in 20 sec. by two cutters on one arbor—there is no idle time. As a result *one* piece will now be finished in 10 sec. instead of 30 sec. as before.

Under the first plan presented, that is, when a lot of 100 pieces had to be milled, the cost per hour was $87^1/_2$ cents. An entire year's production at that rate would have cost $2400 \times 87^1/_2 =$ $2100.

Apart from the cost due to special devices introduced in the last plan, the cost of a year's production will be again $2100 but the value of the product will be three times as much or $6300. The additional value obtained permits the purchase of a certain amount of equipment needed for the new method.

Calculating the Amount That Can Be Spent for Special Equipment for Performing Single Operations

It is now possible to construct a formula which will show the amount of money which may be spent for special equipment for the performance of *single* operations. Let

v = value of work in one year by old method
v_1 = value of work in one year by new method if production is uninterrupted
t = estimated number of years
$fv_1 - v$ = gain per year
P = amount to be spent for special equipment
p_1 = percentage of interest charge

Then $tp_1 \times P + P$ is total amount spent at the end of t years, and this amount should be less than the amount of gain in that period.

$$tp_1 \times P + P < t(fv_1 - v)$$

$$P \times (tt(p_1 + 1) < fv_1 - v)$$

or

$$P < \frac{t(fv_1 - v)}{tp_1 + 1}$$

This formula applies when the equipment has no appreciable scrap value and cannot be used for some other standard operations.

If the estimated number of years of usefulness is so large that the regular factor of depreciation can be figured, then the formula becomes

$$pP < fv - v$$

or

$$P < \frac{fv - v}{p}$$

In the foregoing example the chucking time was assumed to be greater than the cutting time. Conditions are somewhat modified when the reverse is true. As an example, the drilling and spot facing of the two bolt holes will be considered. Assume that the time for drilling a hole = 15 sec. and time for chucking in a simple fixture = 5 sec. Then, if a single drill were used, the time for drilling two holes would be $15 + 15 + 5 = 35$ sec.

If the cost of machine and floor space is $1000, the wage per hour 75 cents, the time for set-up 25 min., and the quantity 100, then the cost per piece is calculated as follows:

Machine cost per hour	$0.0625
Wage cost per hour	0.75
Total cost per hour	$0.8125
Time for drilling 100 pieces	3500 sec.
Time for set-up	1500 sec.
Total time = 5000 sec. = $83^1/_3$ min.	
Total cost = $1.13	
C_u = 1.13 cents	

Leaving for the present the spot facing and chamfering out of the problem, it may be well to see whether and when a two-spindle drill head will be economical. Assuming the cost of this device to be $100, the question is, how many holes must be drilled before this cost is absorbed.

On every piece a gain will be made of 15 sec., the money value of which is $(15/3600) \times 81^1/_4$ cents. The number of pieces to be operated on to absorb $100 is therefore

$$\frac{100 \times 100}{81^1/_4 \times \frac{15}{3600}} = 30{,}000$$

If the two-spindle head is adjustable so that it can be used for other work as well, and if such work is available, it will be sufficient to absorb a proportionate part of the $100, and if such work is of regular recurrence so that the device becomes a part of regular shop equipment, a proportionate part of 15 per cent of $100 only must be absorbed.

In addition to drilling there is also spot facing and chamfering. The most common arrangement for performing such operations is a gang drill in which one spindle is used for drilling, one for spot facing, and one for chamfering.

Assuming the time required for spot facing to be 8 sec. and for chamfering 2 sec. with 2 sec. for each of the three movements from spindle to spindle, the total time for the combined operation is 51 sec.

The time for set-up also is increased, say, to 40 min., making the total time for 100 pieces 5100 + 2400 = 7500 sec. = 125 min. The cost per 100 pieces = $1.69, and C_u = 1.69 cents.

It remains to be investigated what can be done if practically unlimited quantities are to be worked up, and it should be noted that single operations are no longer being dealt with but with a combination of operations, though of the simplest kind.

The longest cutting operation is 15 sec. and it would be a simple matter to arrange a number of spindles so that all operations were performed simultaneously in that time. This would require a multiple-spindle drill with six active spindles, two for drilling, two for spot facing, and two for chamfering. There would be four fixtures, three of them under the spindles and one at the loading position. This arrangement involves an indexing table, which may be operated by hand. If the operation of indexing requires 2 sec., then a piece will be completed in 17 sec. instead of in 51 sec.

However, this arrangement does not give the highest possible economy, for the machine is busy 15 sec. and the operator only 5 (in addition to the indexing). To keep the operator busy it will be necessary to have him load 3 pieces while the machine drills. This would mean that 18 spindles and 12 fixtures are required, while the table indexes to 4 positions. Under these conditions three pieces will be finished in 15 + 2 = 17 sec.

Under the conditions assumed for the small lot the cost of the operation was 81¼ cents per hour, or $1950 per year. The output was one piece every 51 sec. while now it is three pieces every 17 sec., so that the output is nine times as large and therefore the value of a year's output has been increased by 8 × $1950 = $15,600. If there is a fair degree of certainty that the article will be manufactured for two years then the total gain is $31,200, and any amount below this sum would be justified for special equipment. However, here again the factor *f* should be considered, and furthermore it should be kept in mind that there should be a large margin of profit in sight before such special equipment is purchased. On the other hand, such equipment as has been indicated here is not necessarily strictly special; it may be standard—though not of general utility—so far as the machine is concerned and special in regard to fixtures. It should further be kept in mind that the output of such a plant would be very large indeed, and that it might not be kept fully occupied all the time.

Before proceeding with the study of the ultimate economy of the entire piece, the author wishes to call attention to the fact that no attempt has been made to exhaust all possible ways of accomplishing the results, and further, that the figures for feed, speed, chucking, time, etc., were assumed. Such items should be determined by actual observation and by analysis. The author merely attempted to show how factors, once determined, may be *coördinated* and combined.

Analyzing the Cost of Combined Operations

The connecting rod shown in Fig. 1 is a drop forging. The rod and cap are forged in one piece, the sawing apart being one of the last operations. There are two holes to be produced with a rather high degree of accuracy, and there are further a number of minor operations such as drilling, tapping, facing, milling, and sawing.

There are two possible ways in which the cost of machinery may be reduced: by reducing the cost of the individual operations, and by combining operations. It is a comparatively simple matter to compare various methods and their costs when single operations are being analyzed. Quantity to be made, equipment on hand, and cost of equipment to be bought are controlling elements, taking it for granted that the necessary skill required for any method under consideration is available.

To analyze the effect of various combinations is a more complicated problem. At first glance it would appear as if an almost unlimited variety of combinations are possible, but a little study soon shows this not to be the case. Some combinations are not possible, others are clearly not practicable, and still others are so evident that they are hardly considered as combinations at all.

Operations may be combined for various reasons such as (*a*) to secure greater accuracy; (*b*) to avoid handling; and (*c*) for the sake of economy. Whatever is necessary to secure the required accuracy must be done, regardless of economy, so that this phase of

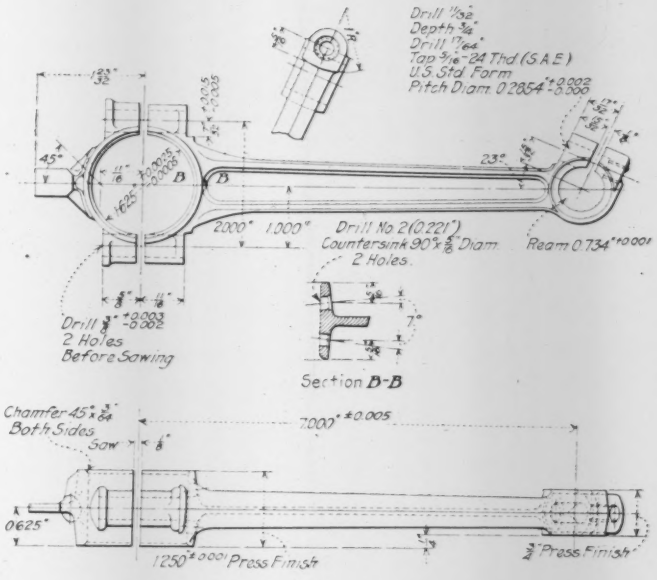

FIG. 1 DROP-FORGED AUTOMOBILE CONNECTING ROD, THE MACHINING OPERATIONS ON WHICH ARE ANALYZED

the matter does not need to be considered. The third case, which really includes the second, is the problem with which this paper deals.

If the various operations to be done are denoted by 1, 2, 3, etc., and the times required are A_1, A_2, A_3, respectively, then the greatest possible economy will be reached if all of these operations are performed at the same time, and the time required will be A_m (that of the longest of all the individual operations).

It should be kept in mind that this refers to the labor cost only. The overhead incident to such a combination may, and often does, wipe out the saving in labor cost. Besides, the cases where it is practical to combine all of the operations, are few and far apart. Nevertheless this ideal should be kept in view, and the proper way is to ascertain to what extent it can be realized.

In the case under consideration there are altogether 26 operations, the longest individual one being either the drilling of the large hole or else the sawing of the cap from the body. A detailed analysis of these two operations would show that the drilling requires approximately 100 sec. while the milling can be done in about 30 sec.

The Ideal Scheme, its Advantages and Disadvantages

The duration of the longest operation is now established as 100 sec. The ideal scheme, therefore, is the one which provides for the performance of all of the operations in this length of time.

Before making a study of the conditions which may prevent us from reaching this ideal, the advantages and disadvantages of such a scheme should be considered in a general way; and the engineer or executive considering such a scheme should keep in mind that while a single disadvantage may at times neutralize all of the advantages, on the other hand, disadvantages, like troubles, are things which either exist in our minds only or else can be overcome by them.

The advantages are:
- Minimum labor cost
- Minimum floor space
- Minimum stock and parts in process
- Minimum handling
- Minimum inspection
- Minimum losses on account of faulty operations
- Maximum accuracy
- Maximum assurance of proper relations of the various elements.

The main disadvantages are:
- The fact that special machinery is required
- The cost of equipment
- The low value of equipment in case of disposal
- The uncertainty of the life of the piece
- The fact that breakage of one tool stops all production
- The fact that stand-by machinery is required
- The fact that the machinery requires attention of a high order, and that the factor f is necessarily low.

The connecting rod forming the subject of this analysis lends itself well to the combining of practically all operations—that is, from a purely technical standpoint. A machine can be readily imagined which would perform all the operations simultaneously. This fact reduces to two the three items which as a rule should be considered, namely, the technical possibility, the technical practicability, and the economical practicability.

When it is stated that all operations can be done simultaneously, it is not meant that all the tools shall work at the same time on one piece, but that a station type of machine could be constructed which would permit of performing all, or almost all, of the operations with one chucking. Such machines are usually built with a turret. A certain number of operations are performed at every position of the turret but one—the loading and unloading position. As a rule, the design of such a machine offers fewer difficulties than that of a standard commercial tool, first, because the machine does not need to take in a wide range of shapes and sizes but needs adjustments only for wear of spindles, slides, and tool, and secondly, because they do not have to compete on price.

On the other hand, the building of such a machine requires the highest possible accuracy if the piece of work shall be reasonably accurate. The turret must index with great precision, and the chucks or work-holding devices in general must all be located in the same relation to the center of the turret and to the index slot.

Not only are the errors of the machines duplicated in the piece, but the relative position of the holes does not remain constant. The author has found it necessary to employ special methods in the design and construction of such machines to secure a degree of accuracy of a higher order than that required for ordinary machine tools. It is this need for unusual accuracy which causes machines of this kind to be so expensive. However, designers have often made the mistake of ignoring the special requirements of individual cases. In the present instance no great accuracy is required anywhere, and even those dimensions which do not permit of a large variation are between points which can be located in one station, so that there is no fear of undue accumulation of errors.

The piece would be clamped on the circumference of the turret. In the first position the two main holes would be drilled, both sides of the large hole would be chamfered, and the tops and bottoms of the bolt-hole lugs would be straddle milled. In the second position the bolt holes and the binder-screw hole would be drilled and the bolt holes chamfered. In the third position all oil holes would be drilled and the binder-screw hole tapped. The fourth position would take care of the reaming of the two main holes, and the fifth position of the sawing for the binder screw and the cap, and straddle milling the splasher.

It should be emphasized here that this is not the only possible arrangement but merely one which is feasible and which is given for the sake of focusing on a definite method.

The next step is to consider this arrangement from the standpoint of practicability. It is seen at once that to separate the cap from the body in this machine materially reduces the chances for a solid support of the head against the drill. This appears to be of enough importance to warrant dropping this operation.

Countersinking the back of the head also seems to be doubtful. However, a closer examination shows that this operation can be included without danger of affecting the success of the other operations.

Economic Soundness of Method Proposed

The main question remains yet to be answered: namely, whether such a method would be economically sound. Before going deeply into this matter it should be remarked that a machine such as was imagined would be capable of a certain amount of adjustment so that changes in the dimensions and even in the distances of the holes would not make it useless. The construction of the connecting rod would have to be changed in its essentials before the machine would become obsolete. This consideration affects the estimate of the useful life of the machine.

Assuming that a first machine costs $25,000, that a second or stand-by machine costs $15,000, and that the useful life of these machines is five years, the following is found;

Cost of machines	$40,000
5 years' interest	12,000
Total	$52,000
Cost per year	$10,400

Estimating that there are 2400 working hours in a year, the production will be $2400 \times 3600/100 = 86{,}400$ pieces, because it takes 100 sec. per operation. This shows that the machine cost per piece will be a little over 12 cents.

If the quantity to be produced is sufficiently large this machine cost per piece may be reduced in various ways. For instance, double sets of tools and chucks may be provided so that the operator chucks two pieces instead of one; or that part of the plant may be run on the two- or three-shift plan, or else the longest operation, the drilling of the main hole, may be split.

The first method is not desirable, partly because it makes the machine too large and complicated, and partly because some of the duplicate tools will be in each other's way. The second method cannot be seriously considered except when other parts of the plant must be run in the same way. The third plan is entirely practical, adds only one station, so that the size of the machine is not much increased, and actually simplifies matters by distributing the tools more evenly. If this third method is followed the machine cost per piece becomes 6 cents.

It may be noticed that the machine was supposed to work all the time, no allowance having been made for tool setting and adjustment. This is proper where there is a stand-by machine, as one machine can be in production while the other is being made ready. A small percentage may have to be deducted for absence of the operator, and this may be met by considering the machine cost to be $6\frac{1}{2}$ cents.

Single operations performed according to modern methods, using multiple-spindle drill presses and turntables—in short, methods which compare very well with those used in the most productive shops—bring the total time for these operations up to 333 sec. per rod. The single machine therefore saves 233 sec. per piece or not quite 4 min. Estimating the labor cost at 75 cents per hour, the saving in labor cost would be 5 cents per piece, which is less than the machine cost. Against this the machine cost for the single operations must be figured.

By splitting the drilling operation and thus reducing the time per piece to 50 sec. the saving per piece becomes practically 6 cents, so that even in this case no profit is shown.

If the production requires a piece to be finished every 50 sec. and it takes 333 sec. to finish one by single operations, then there must be more than one set of machines in use; not all the machines, however, would have to be duplicated. This brings the machine cost for the single operations somewhat higher, but not high enough to justify the building of special machinery with its chance of failure and its almost certain period of development.

If the quantities required are larger, and especially if the life of the piece is certain to be a great many years, another story would be told.

Notwithstanding the fact that the actual machinery cost may not be reduced, there are cases where such special machinery

(*Continued on page 362*)

Material-Handling Problems Encountered in the Assembly of Automobiles

By M. R. DENISON,[1] SOUTH BEND, IND.

This paper is a description of the time- and labor-saving methods devised for the handling and inspection of raw materials and finished parts in a large modern automobile-manufacturing plant. It deals with the functioning of stores divisions as service departments, loss of material, reductions effected in amount of clerical labor required, instruction of store-room men, location of store rooms, handling sheet metal, transportation, final car assembly, etc.

INVESTIGATION with a view to economy is always finding problems to solve, and the competitive nature of its product has forced the automotive industry to become highly specialized in this respect. This paper will not be built on theoretical discussion, for only matters that have been accomplished or have sure possibilities of reasonable accomplishment will be taken up, and more frequent reference must be made, therefore, to conditions at the Studebaker plant than would otherwise be the case.

When the automotive plants began to reach a competitive point they started in to reduce costs by improving productive operations and equipment, and after these items had been covered in a general way and much accomplished, the batteries of efficiency engineers and layout and methods department men were turned on nonproductive labor and equipment, and the orders were apparently not to cease firing. We have seen the day pass when hand truckers slowly plodded one after the other, each with one motor on a truck, from the motor-assembly department in one building, across an open yard space to the block-test building. Both buildings are now one and a power conveyor or crane does the moving. Where formerly each machining department had a group of truckers under the foremen to handle parts from one operation to another, in the Studebaker South Bend machine shop, a one-story building 480 by 520 ft. in which 850 productive men are working on 2200 operations on 431 parts, the operations are entirely progressive, the machines and benches being arranged so that parts move from the two ends of the building to the center bay—where the inspection benches are located, and two hand truckers only are employed on productive material. Parts are moved from one operation to the next and finally to the inspection bay by the operators themselves with the aid of belt, overhead chain, or gravity roller conveyors, or by chutes inclined to lead to a cast-iron bench at the next operation. Further, processed work is no longer passed through in lots and productive job tickets provided for operators to ring in and out at each machine change, from which tickets costs are obtained with a great deal of clerical effort. And it would be possible to enumerate many other such changes which have resulted ultimately in lowering costs of production. But for every accomplishment a new problem arises.

Stores Divisions as Service Departments

As a result of studies that have been made, most of the automobile-plant organizations have come to recognize that the handling of material is a task important enough to call for a separate division of workers. On this basis the stores division becomes a service department to the productive manufacturing departments, for it delivers the work at the right time, takes away the finished material, and keeps the foreman thoroughly aware of his standing on schedules. It is a difficult problem in itself to get the storekeepers and store-room men to realize that they are a service department and that the service they give must be the first consideration. It is recognized that the first principle of automobile manufacture is to produce the cars daily as scheduled, but in the recent past this principle has been somewhat reduced in scope, so that now expense is being considered carefully before radical steps are taken, even though production is slowed temporarily as a result. The foremen must believe in the storekeeper and feel that the stores men are handling the material as he wishes. This confidence is the first requisite of a successful material-handling division. In cases where there is any question at all as to who is correct the foremen should receive service as he requests, the correctness of the move being considered later and stock deliveries altered, if necessary, after an investigation has been made.

The Problem of Loss of Material

The problem of what is termed "loss of material" is one of serious import, and when analyzed it is found to be due to one of three things: wrong receipts, wrong usage, or unreported scrap, under which head can also be included theft. These are all tremendously important items. If we are really attempting to save money in costs, we will not recount material as it is delivered from the receiving department to stores, except in a small percentage of cases. The actual correct receipt of material is therefore exceedingly important. Receiving-department men must be carefully and thoroughly instructed that the records on which the management depends start from their own personal counts. These counts should be made without the aid of any packing ticket or invoice, and upon completion should be compared with the packing ticket or invoice by the head checker.

The real solution for any problem is to have the right man at the right place, but particularly is this true in receiving departments. The question of disbursing and usage of material is, fortunately, in the case of the Studebaker Corporation under good control. Stock is delivered absolutely in sets, based on car specifications, and this issue of material is made to assembly departments on a schedule basis, every day to the piece, which schedule is in practically all cases the same as the finished daily car schedule on the final-assembly line. Banks are established which are quite close in assembly departments, and store rooms hold to these banks by issuing material to schedule plus bank only. In disbursing material counting scales are used to a very great extent on small parts, as it is believed that greater accuracy is thus obtained.

Delivery slips are made out by each storekeeper every afternoon showing the exact amount on every part to go to the assembly line for the next day's work. The store-room men then put the stock up in accordance with their orders and place it on benches which are just inside wickets in the fence between the store room and the department. These wickets are kept closed until late in the afternoon, when they are opened up and stock is thereby made available for assemblers. The latter move the material from the wicket bench to the point of assembly, where the amount is not large enough to require a special means of conveyance.

Reduction Effected in Amount of Clerical Labor Required

While on this part of the subject, the author would point out that the only clerical work done in the finished-stock rooms of the concern under consideration is the writing up daily of the delivery orders mentioned above. There are no stores-quantity cards or store-room clerks except on bulk material such as sheet metal, forging steel, and textiles. Why isn't it logical to schedule delivery of parts from finished-stock rooms to assembly lines, the same as manufacturing departments are scheduled to deliver stock to stores? In the immediate future the delivery orders mentioned above will be made out by the scheduling department, or regulation schedule boards will be installed showing how deliveries are to be made daily from stores. The present arrangement gives the storekeeper a better chance to check disbursements, which is his real responsibility, and to see that the time of his men is being utilized to the best advantage, and the proposed change will allow a further improvement. The stores count on material delivered to lines is absolutely accepted unless discrepancy is proved before the stock is used.

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[1] Superintendent of Stores Division, Studebaker Corporation.

Contributed by the Materials Handling Division and presented at the Spring Meeting, Cleveland, Ohio, May 26 to 29, 1924, of The American Society of Mechanical Engineers. All papers are subject to revision.

The third item, the matter of unreported scrap, constitutes a problem which seems to be one of the most serious that has developed. This loss is found quickly in assembly departments, due to the fact that departments operating with narrow banks cannot keep up to schedule if parts are short.

An interesting way of handling this sort of loss has been devised which also helps to cure the trouble. When not enough material is available to make schedule, foremen must make out requisitions therefor, which are then passed to the works accounting department, priced, and charged to the department's scrap and repair account. This account is one which is budgeted in every department on a per-car basis, and any unusual situation is noted quickly for the reason that 10-day budget reports are made up and delivered to each department foreman and copies to his division superintendent.

However, difficulty is experienced with scrap getting away in the machining, forging, and stamping divisions, and to prevent this entirely will cost considerable, either in the way of frequent inventories of individual parts or quarterly inventories of departments. The only inexpensive solution is to gain the confidence of the foremen and floor inspectors as well as that of the operators—have them understand the importance from a record standpoint, and educate them that they must be fair in the matter to the management. It might be suggested that some improvement will be made when banks of work in process are narrowed to the point where the trouble may be found immediately after it occurs. The disposal of all scrap material should be handled by stores with the approval of the inspection department, in order that part number, quantity, and other necessary information can be verified as material moves to, or is received by, the scrap department.

Records Hitherto Considered Indispensable Now Discontinued

After some study it has been found possible to discontinue certain records which at first were considered indispensable, for example, stores-quantity cards. Banks of material have been carefully laid out in every department as well as in every store room, and in this way the total to be carried in the plant is learned. The stores division schedules material on the follow-up and purchasing department on a basis of car requirements plus the total bank on the part plus any sundries such as scrap or service-plant needs. This scheduling is made from a material-control record maintained in the production office, which record shows receipts, usage in cars (entered weekly), also any sundries and the balance available. This balance available is computed on every part or item weekly into the day's supply and carried forward to a graphic tape board. On these boards every part is separated into groups by the class of bank. That is, every part that goes into a motor on which a two weeks' supply is carried is side by side, and if the material situation is satisfactory every tape on these parts will be pulled down to an 11-day point, which represents a two-weeks' period.

In view of this clear record, which indicated the amount available in the plant, the question arose, "Why have stores-quantity cards," and the answer was their elimination. When before the store-room cards gave a check on receipts, a register is now maintained on all receiving reports to make sure they are going across the records. A cross-check has also been installed by sending the office copy of the receiving report to the store room receiving the goods, the store room returning their copy to the office as an acknowledgment of correct receipt. Storekeepers then file the office copy by part number in the store room. No doubt the question will now be raised as to how the store rooms report shortages of material when they have no records. A six days' supply of each purchased finished part is carried in a separate location from the regular stock, and when through lack of material the storekeeper is forced to remove any material from this emergency location, he advises the production office. The part is then checked against day's supply on the control ledgers to make sure they are in accord, and reported to the follow-up men. In practically all cases it is found that the records have evidenced the shortage before and that the stock is near at hand. This routine has a considerable bearing on material handling for the reason that if layouts are properly made, stock will not be received ahead of schedule without additional work. The graphic tape boards mentioned above are designed as much to indicate when material is getting in too soon as to prevent shortage of material, with the consequent delay.

On manufactured parts the bank of finished stock is so small that any foreman who is behind schedule knows that he is holding back production to some extent somewhere along the line.

The Proper Location of Store Rooms

The physical location of store rooms is now receiving a great deal of thought. The stock must be kept in as close proximity to the point of use as possible, and stock rooms should therefore parallel assembly lines and should be of the same length. They should also be located so that stock cannot get out into assembly departments without going through a store room. Rough stores should parallel the manufacturing departments they serve, and be in close proximity to them. The equipment in these stores should be installed entirely with a view to decreasing cost. In the case of the Studebaker shops it has been found expedient to install cranes in nearly one-half of the store rooms, and on such items as forging steel and sheet metal arrangements have been perfected so that no hand labor is required in handling after the steel is out of the car in which it was received. Yards for forging steel are provided with overhead cab cranes on both sides of the forge-shop building. A shear house is located at one end of each yard, and billets after shearing are delivered by magnet into chutes leading from the steel yard through the wall of the building to the heat-treating furnaces which, in turn, are located above the forging hammers. Heated billets are dropped down another chute to the hammerman as he completes a forging. After forging, the parts are moved through the remaining forge-shop operations in steel baskets by overhead cab cranes which operate over every foot of the forge-shop building.

Handling Sheet Metal

Sheet metal is handled entirely by crane after unloading. It has been found a good plan to arrange the lifting and piling of this material, which is one of the most difficult to handle, so that a certain number of sheets of any gage are handled at each lift by the crane. By using spacers of wood in each pile of sheets, it is possible not only to handle the material quickly and safely, but to secure immediately an accurate inventory at any time. Safety crane hooks for gripping piles of sheets have been designed, by which almost any quantity of sheets can be handled at one time. Four clamps, two on a side, are used, which "toe in" on the sides of the pile and which can be inserted in the openings made by the wooden spacers. When the load starts to rise, the design is such that the "toes" pull in toward the center line of the sheets and stay there. In fact, the heavier the load, the greater the safety factor is found to be.

The problem of shipping sheet metal needs attention, with a view to having the stock loaded by mechanical means in a car from which it can be unloaded by the same apparatus. This could be a small electric-crane-equipped tractor that could run into or out of a box car with a load of steel. It also could be an overhead crane loading steel into a gondola car, on which car would be placed after loading was completed, by crane, a removable cover of some sort. The shop under consideration has every convenience for handling sheet metal, but its men still lift sheets or strips from the pile in the car by hand and place them on trucks.

Tractor and Trailer Transportation

The matter of transportation has received a great deal of attention and has netted substantial savings for any plant that has gone thoroughly into it. In an automobile plant of any size the transportation department should be organized—and already is, in many instances—exactly on the same basis as a railroad. Tractors should be the substitute for engines, and drivers for engineers. Different types of trucks should replace freight cars, a despatcher's office should be maintained, every tractor should have a scheduled route to follow, and terminal points should be established where trucks will be dropped and trucks for other points added. Drivers in the Studebaker plants ring special time cards at each stopping point on their routes on time clocks, and if for any reason they are delayed they must telephone the despatcher from the first stopping point. The only difference between this system and that of the New York Central is that no firemen or brakemen are needed and no passengers are carried. The driver is the whole

crew except for the assistance he receives in that his train is coupled up for him at stopping points by other men.

This system immediately emphasizes the advisibility of keeping material in trucks on wheels ready to move, and a determined effort is made to accomplish this. All material in semi-finished stores—that is, aluminum, malleable, and gray-iron castings, forgings, stampings, etc., that are ready for machining operations—is carried practically in all cases in what are called "box trucks." These are designed so they may be piled one on top of another by small cranes that travel the full length of the floor in each bay of the building. Trains of material are made up with trucks in proper sequence and leave a department such as this every 60 min., entering the machine shop at one end of the building, and continuing the full width of the shop, dropping trucks of material at the proper cross aisle in which the part is machined. As parts are inspected after machining and O.K.'d by inspectors, they are placed in trucks —or if necessary in special containers—by the inspectors. A truck or container is kept under the end of each inspection bench at all times. Just prior to the time the tractor is due in the inspection bay for a pull out, all trucks are gathered together in the right rotation for delivery and coupled up. In every case an empty truck or box must replace the one removed from the inspection bench.

It has been found necessary to build a great many special boxes, containers, or trucks for individual items, due to their requiring protection on account of enamel, close limits, odd size, etc. All gears, crankshafts, connecting rods, camshafts, motor valves, fenders and all other enameled parts, and innumerable additional items require special trucks or boxes. Every one will see how exceedingly difficult it is to have the right amount of containers, and to have them at the right place when they are wanted. The greatest aid in removing this difficulty is regular movement of the goods and prevention of trucks or boxes for the same item accumulating at one point. This means above all their prompt return when emptied. One compensation for this trouble is found in the fact that the necessity of hand counting the part is largely eliminated, for the box or truck can easily be marked with the part number and the quantity it holds.

After tractors have pulled material into the building to which it is consigned, if there is a vertical movement required, the material is handled in practically all cases by crane. Elevators are utilized in a few instances, but the overhead crane, running the full length of a building and serving all floors by means of projecting balconies, gives quick service where attention is needed at once and causes no such amount of waiting as is usually the case with an elevator. Upon receipt in finished stock, if the piece is in a special box it is left there until used, otherwise it is placed in the proper bin for storage.

Gasoline tractors are utilized with economy for work which is entirely outside. In South Bend all incoming local freight from freight houses is handled with gasoline tractors pulling trailers directly into the receiving departments. The advantages of this arrangement are that the power plant is always busy, helpers are not needed to accompany the driver, and the original cost of installation is much less expensive than purchasing a fleet of trucks.

INSTRUCTION OF STORE-ROOM MEN

One of the difficulties to be overcome in the automobile plant is the carelessness of store-room men in handling expensive items which are easily damaged. This, of course, is very largely due to lack of instruction at the time the men begin work. For the good of all industry this should be hammered home particularly to storekeepers: "Properly instruct new men." It is to be expected that if the men in store rooms are careless, then operators or assemblers who later get the parts will handle them in the same manner, and the problem then is to find who really is at fault, for one is very easily able to say the other is to blame. A carefully prepared set of instructions for men to read prior to starting to work in store rooms is to be recommended, as this method of acquainting men with their work will do away with the possibility of a storekeeper's overlooking an important part of a job, which he may easily do, in instructing a man orally.

One very amazing development in the automobile plant is how, in spite of the variety of parts handled and operations performed, so many seemingly small things have received such individual attention. Out of this there have come innumerable arrangements for handling material that are very practical and helpful.

VARIOUS TIME- AND LABOR-SAVING METHODS OF HANDLING AND INSPECTING MATERIALS

So it is one finds in quite a few places a conveyor possibly traveling with its return twice as far as it needs to in order to deliver the material it carries, but by this extra travel it allows the store-room employee to go to some other work for 30 min. after the conveyor is filled.

A great number of parts can be found on which special arrangements have been made with outside suppliers in regard to methods of packing and loading, each item having been thought out individually. For example, motor valves are shipped to the Studebaker plant in racks, each rack holding 120 valves. Six racks are placed in a box by the outside vendor. Upon receipt the racks are removed from the boxes and are sent to the motor stock room. The valves are then kept in the same rack in which they were received until assembled into the motor. After a rack is emptied its ends, being hinged, are folded back, and as many empties as possible are tied together and shipped back to the vendor. By this method counting and handling is kept at a minimum, and even though freight must be paid on the return of the racks, a saving is effected.

In some departments the work of inspection, counting, and billing material out is combined and a man saved on the assignment.

At the point where rear axles are placed on the final line conveyor, there has been built an automatic pickup that lifts the axle at the proper time and locates it on the conveyor chain. In another location pistons are machined in one long, single line of machines and all operations are fast. Midway down this line an aisle must be traversed, which is rather busy with traffic, and this has caused the building of a semi-circular conveyor that arches up over the aisle and carries the line of pistons on to the next operator, over the heads of those who may be using the aisle.

Automatic counters at inspection benches are now being experimented with. A chute has been installed leading from the bench down into a box or truck, with the automatic counter operated by a shutter or series of shutters as the pieces go down the chute. This eliminates one handling and also has possibilities of giving better counts than when pieces are counted by hand.

A circular gravity roller conveyor operating from the third to the first floor not only serves as a conveyance for finished seat cushions but also is sufficient in length to handle the storage of all cushions carried in bank.

Another example is in the machine shop where a considerable number of parts that are later enameled are machined at many different points. These are all conveyed from the point where they are inspected after machining to the enamel department, which is located in one corner of the machine shop, by one overhead chain conveyor 700 ft. long, which passes through each section of the shop as well as the entire length of the inspection bay, and which is equipped with hooks so that the part can either be hung on the chain or placed in a suspended basket.

With each car is shipped what is called a tool-box assembly, in which are placed the usual kit of tools—tire pump, jack, instruction book, grease gun, etc. Sometime ago shortages began to occur in these boxes upon their receipt by dealers. At the suggestion of one of the assemblers a semi-circular table was provided with spaces for each item, and now the assembler first places in each compartment a given number of the proper part, and then when assembly is finished, if any stock is left in any section of the table, boxes are reinspected for shortage before being sealed.

Every car part used by the automobile plant should have banks carefully laid out in every department or store room through which it passes. Here is the real method by which material can be handled with the greatest economy. The banks should be laid out with the idea in mind of carrying the lowest possible inventory, and space assignments should be such that trouble will develop if too much material is on hand at any stage of the operations. After these banks are established, with the approval of the men overseeing the departments through which the parts pass, deliveries should be made rigidly to schedule and, in so far as possible, on a daily basis. Many advantages accrue from this plan, not the least of which is the fact that due to narrow banks foremen themselves must know exactly

at all times where they stand. This does away with "stock chasing" and a great deal of unnecessary follow-up work and second handlings. The Studebaker plant has found the narrowness of its finished banks such that all records on schedule boards must be posted during the night, so that all foremen and superintendents know exactly where every part stands on their arrival in the morning. In addition to this, in certain departments deliveries made during the day are kept posted right up to the minute on a separate board for the foreman so that he may see if the daily delivery is being made. The point has been reached in the machine shops where 80 per cent of the parts made are being put through machining operations and delivered on a daily basis. In assembly departments daily scheduled delivery is lived up to absolutely on every assembly. If the schedule for the month is 7500 and there are 25 working days, stock is delivered to the floor and finished assemblies delivered off the floor at the rate of 300 per day, or if the part is peculiar and the schedule for the month is 25, one is delivered per day.

Parts are more and more being considered on an individual basis, and therefore on a certain malleable-iron casting it may be necessary because of the assembly in which it enters, going through painting operations or some other long course, to carry a two-month's supply. On another malleable-iron casting which is quickly machined and goes at once into a final car operation, the plant can and does get along with less than one week's supply. With this daily flow of material it is essential that stock be available at all times for the departments, and it will become necessary in extreme cases to deliver ahead on one part, if out of another, so that foremen can conserve men-hours. The real way to gain the good-will of a foreman is never to ask him to rush deliveries on any item on which he is up to schedule according to the records. The thing to do is to change his schedule. At the same time it is quite important that some one shall be after him when he drops back. The correct assignment of banks and insistence of daily movement of parts will solve many difficult problems immediately.

Handling Material for the Final Car Assembly

The problem of handling the material for the final car assembly is a story almost in itself, for the reason that the layout must be largely automatic if economy is expected. Here a great many parts of all types and sizes must be handled. At the Studebaker plant the cars are built on three tracks side by side, each track being 400 ft. long. The entire floor above the final assembly is utilized as a store room. Stock racks are made up as they move on a power conveyor past piles and bins of material, each rack containing when assembled all the parts for one car except the motor, axles, frame and body. All nuts, bolts, cotter pins, washers, etc., in exactly the right number for one car are included in trays in each rack It has been found economical to have the washers and nuts assembled to bolts by boys before they are placed in the stock rack. This is done so that when an assembler reaches in a tray for a bolt he gets the parts required to go with it with one move. The trays used for small parts are designed with regard to the position of the man who is to remove the parts and to the side of the car on which he is to work. The rack when assembled in the store room is carried by crane from the store-room conveyor over to the proper one of the three line conveyors, all of which are arranged to come up through the stock room at one end of the floor. It is locked into the conveyor and travels downward at an angle of 45 deg., which necessitates locking the parts to the rack in any case where otherwise they might fall off. A rear and front axle are placed on stands by store-room men between each two racks, and when they reach the assembly floor the frame is put in place, assembled to the axles, and parts are then removed from the stock rack as needed at the various operations. When the semi-completed chassis reaches the point for the assembly of the motor, the latter is dropped by a traveling crane from the store-room floor above directly into place. Bodies are finished on the third floor directly above the point where they are to go on the chassis, and are dropped through two floors by a crane, and into place on the chassis. The car conveyors, of course, move all the time.

With all the models that are built it is quite a problem to set body lines in harmony with the final line, to have stock racks for the right models arrive at the right moment, and to know that motors, wheels, axles, etc., of the correct type are available. When the stock rack reaches the end of the conveyor the car is of course completed and the rack empty; the latter returns by a booster conveyor to the second floor, and starts again on another trip down the stock-room conveyor. In connection with the car-assembly department it is necessary to carry a repair stock room, and an elevator has been utilized for this purpose with bins built right on it, stock being served out through a wicket at the front. The elevator by going up one floor is at a point where its stock can be easily replenished by the store room. A system of lights has also been installed on each of the three floors involved which would lead one to believe he was watching traffic on Fifth Avenue, New York, for a green, a red, and a white light are placed together at the center of each of the three floors, and when any one light is turned on it can be seen the whole length of the building. One light designates the assembly-line floor, another the store room, and the third the body line, and if the final line develops trouble of any sort they turn on the proper light, and the foremen of any floor knows immediately whether his floor is causing trouble or whether some other fellow is at fault.

Material-Handling Problems Encountered in the Assembly of Automobiles

(*Continued from page 328*)

TABLE 4 NUMBER AND HORSEPOWER OF TYPES OF PRIME MOVERS IN THE IRON AND STEEL INDUSTRY 1919, 1914, AND 1909

(Compiled from report by the U. S. Bureau of the Census)

Power	Number of Engines or Motors			Horsepower: Amount			Horsepower: Per Cent Distribution			Horsepower: Average Size of Unit		
	1919	1914	1909	1919	1914	1909	1919	1914	1909	1919	1914	1909
Primary power,[1] total	31,096	13,572	11,337	5,402,349	3,928,826	3,274,400	100.0	100.0	100.0	174	289	289
Owned	8,039	7,202	8,673	4,656,273	3,722,064	3,200,638	85.2	94.7	97.7	579	517	369
Steam	7,718	6,855	8,433	4,106,373	3,440,693	2,989,879	76.0	87.6	91.3	532	510	355
Engines	6,796	...	....	3,243,347	.....	.....	60.0	..	..	478	..	..
Turbines	922	...	...	863,026	.....	.....	16.0	..	..	936	..	..
Internal-combustion engines	278	227	178	540,488	267,789	204,621	10.0	6.8	6.2	1942	1179	1149
Water wheels, turbines and motors	43	120	62	9,412	13,582	6,138	0.2	0.3	0.2	219	113	99
Rented	23,057	6,370	2,664	746,076	206,762	73,762	13.8	5.3	2.3	32	32	28
Electric	23,057	6,370	2,664	743,301	203,805	73,647	13.7	5.2	2.3	32	32	28
Other	...	...	...	2,775	2,957	115	0.1	0.1	..	..	..	..
Electric[1]	92,930	50,968	31,231	2,593,150	1,420,297	851,752	100.0	100.0	100.0	28	28	27
Rented	23,057	6,370	2,664	743,301	203,805	73,647	28.6	14.3	8.6	32	32	28
Generated by establishments reporting	69,873	44,598	28,567	1,849,849	1,216,492	778,105	71.4	85.7	91.4	26	27	27

[1] Motors operated on purchased electric power are rated as primary power.

Provision has been made to install superheaters later.

Feedwater regulators are used.

The fuel used is washed blast-furnace gas, but in order to utilize the sensible heat of the gas as it leaves the blast furnace, plans are being made to use unwashed gas.

Steinbart gas burners are used. In this type of burner the sizes of the air and gas passages are such that the correct proportions of air and gas are fed when the pressure of each is the same. The pressure of the air is controlled by a Hagan regulator which is operated by the gas pressure. Another Hagan regulator operated by the steam pressure controls the main gas valve of the battery.

In cases of emergencies, by-product tar is used as fuel. The necessary burners are permanently installed in the rear wall of the firebox.

The following instruments are installed on each boiler: Steam-flow meter, gas-flow meter, recording thermometer for flue-gas temperature, indicating draft gages showing the pressures at various parts of the setting, and a steam-pressure gage.

For the plant are installed a venturi feedwater meter, recording gages showing the steam and gas pressures, and a recording thermometer for the feedwater temperature.

The Relation of Mechanical Engineering to Management in the Textile Industry

By E. H. McKITTERICK,[1] BOSTON, MASS.

While the actual manufacturing is the least important item in the management of cotton mills, the mechanical engineer has a wide opportunity open to him in reducing the cost of manufacture by means of improvements in power, lighting, and heating systems, and in the handling of goods between processes.

MANAGEMENT deals primarily with going concerns, with producing units, and for that reason it is the purpose of this paper to consider the engineer's part in the routine of operation rather than in the possibly more important field of new construction.

Without considering the financial side, it may be assumed that in textiles, management's responsibility consists of three main factors, namely, the purchase of raw material, the sale of the finished goods, and the manufacture of these goods. It is in this third item that mechanical engineering becomes a definite function of management, a function that is self-evident when the methods of production are examined.

Cotton manufacture consists in cleaning and in paralleling the cotton fiber; in twisting the fiber into yarn and in weaving the yarn into cloth. The process is continuous, the machinery highly standardized and semi-automatic in character, and the volume of production is governed rather by the speed of the machine than by the skill of the operator. If this somewhat sketchy outline indicates a field for the engineer, it might be well to consider the management's problem, first as applied to the individual mill and then to the group of mills with a central administrative office, with the idea of indicating wherein mechanical engineering can best function.

The Individual Mill

The operation of the mill is largely governed by the following factors: economy of production, quality of production, and the securing of a stable working force.

Because of the competitive nature of the cotton-goods market, these items are controlled by the necessity for a large volume of production at the lowest possible cost. The details making up the costs are material, labor, power, heat and light, overhead, and interest. Barring the last two items these are all factors of production.

Material. This is the raw cotton with an allowance for waste made during processing. When it is considered that the waste in a fine-goods mill is 33 per cent of the input, and that in an ordinary duck mill it is about 15 per cent, it can readily be seen that it is quite an important factor in the cost. This waste consists of dirt, neps, noils, fly, short fiber, and all process waste beyond the fine frames. The value of engineering thinking tending toward the reduction of these percentages is self-evident.

Labor may be divided into machine tenders, those who handle the product between processes, repair labor, cleaners, etc. The labor cost runs from 35 per cent of the total in a fine-goods mill to about 9 per cent in a duck mill. As has been said, the machine is the major factor of production. The operative functions mainly as a tender, and it is a common commentary on the textile industry that in a well-run mill most of the operatives will be found sitting down apparently idle.

A consideration of these facts may explain the apparently backward attitude of textile men toward time and motion studies. Unfortunately in many cases there has been an attempt to transfer bodily the intricate methods and nomenclature as developed in metal working without considering the basic differences in the two industries. In the present stage of cotton manufacture, engineering effort applied to straight-line production, the more efficient grouping of processes, and the study of proper machine speeds and settings, will undoubtedly result in a greater gain than if applied to the personnel. This is not intended to disparage the excellent work now being done in training operatives nor to undervalue the great gain that will accrue to the industry when the Taylor principles are developed to meet the peculiar needs of textiles.

The labor expended in handling the product between processes is a direct challenge to engineering. In a mill employing 2200 operatives, 200 are employed in this capacity. Because of the fragile nature of the package, particularly through the processes up to and including spinning, the ordinary methods of mechanical handling result in waste and in poorly running work. In one of the New England mills the engineers have developed a system of conveyors, beginning at the opening room and ending at the cloth room, i.e., where the finished product has its final inspection. These conveyors reduce the labor for handling to a minimum, and by acting as a reservoir for stock in process, practically eliminate machine stoppage due to lack of material. The entire system of operation in the mill has been based on the conveyor method, an inadvertent application of the Taylor principles, which in this case has reduced the stoppage for doffing to a remarkable degree, even though this has involved radical departures from established practice. The results are a saving of $27,000 per year, considering only the conveyor, and it is a significant commentary on the new method of operation that this mill competes successfully with mills in the South making the same product, in spite of the fact that the average wage now paid is higher than at the war peak. It is of especial interest from a management standpoint that the overseers and second hands are thoroughly "sold" as to the value of the conveyors, and have themselves developed several improvements, a fact that reflects considerable credit on the managerial ability of the engineer who designed and installed the equipment.

Power. The generation and distribution of power, whether electrical or mechanical, presents a wide field for the services of engineers, and whenever existing plants require added power or a rearrangement of machinery, an engineering problem arises as to the best and most economical method to use. These problems are extremely varied in their size, location, and character, and while most large plants have competent operating engineers, their viewpoint is sometimes not as broad as that of outside consulting engineers with many years of experience in a great number of plants. Where the change is an important one involving large sums of money, outside engineering consultation is a necessity.

Lighting. The past few years have seen tremendous progress made by the manufacturers in the efficiency of lamps and fixtures, and it has been said that any mill or manufacturing plant which has not entirely renewed its lighting system within the past ten years will find it a paying investment to do so at once. The value of adequate lighting in decreasing industrial accidents is too well established to be questioned. Its value in reducing spoilage is also well established, but it is of course difficult to determine what proportion of such a decrease is attributable to lighting alone. In a certain fine-goods mill, following a radical change in the lighting system, the percentage of seconds was reduced from 3 per cent to 2 per cent, a saving of 16,000 yards a year. Much of this saving was undoubtedly due to proper lighting.

Heating and Fuel Consumption. In plants which require the use of steam in manufacturing processes there is usually a favorable opportunity for the plant to generate its own power up to the point where the total amount of exhaust steam produced can be used in process work. Under this arrangement the power generated is a by-product, as the steam must be produced anyway, and under these conditions power is obtained very cheaply. Engineers are often able to discover where exhaust steam from engines or turbines may be used in place of high-pressure steam, and to effect great economies by such changes.

[1] Lockwood, Greene & Co., Managers.

Contributed by the Management Division and presented at the Annual Meeting, New York, December 3 to 6, 1923, of The American Society of Mechanical Engineers. All papers are subject to revision.

In plants requiring the use of large quantities of warm or hot water, very favorable opportunities occur for the storage of waste heat from any source, and the proper system of hot-water storage and distribution is often a source of great saving.

Engineers recently were called in consultation on a large worsted mill where the management felt that power and fuel costs were excessive, although they were at a loss to know just what ought to be done. One idea they had was to build a new power plant at the cost of about half a million dollars to remedy this situation. After careful study by experienced engineers it was found that their present power plant, with an expenditure of less than $100,000 for new equipment and building repairs, could be made entirely serviceable for a great number of years. It was further found that at this same plant they were running an engine and a turbine, both condensing, and discharging large quantities of water from the condenser into the river. At the opposite end of their plant they were taking quantities of cold water out of the river and warming it by the use of live steam from their boiler plants for use in the dye house. The engineers discovered that by changing one of the condensers they could deliver clean warm water from these condensers direct to a system of hot-water storage and distribution for the dye house. Strangely enough, the amount of water available from these condensers was exactly the amount which the dye house required. This change was put into effect, and not only was it possible to operate the plant with a considerable reduction in boiler capacity, thus making a new boiler house unnecessary, but also to make a saving of about 25 per cent in the annual fuel bill of the plant. This particular plant offered a most favorable opportunity for this kind of a saving, and while opportunities as good as this are seldom encountered, there are doubtless a great number of somewhat similar situations existing where proper investigation and study would reveal these hidden opportunities.

Stable Working Force. No problem of today is more in the minds of industrial leaders than that of the contentment of the rank and file. The design of mills, and their exterior as well as their interior appearance, have a distinct bearing on the pride that the workers have in their jobs. The character of floors, proper ventilation and humidification, the elimination of unnecessary noise, all tend to increase the operative's comfort and consequently his efficiency. The question of mill villages is more than that of adequate housing. Careful engineering supervision of these projects should insure as great a number as possible of the ordinary conveniences and comforts without, in so doing, materially increasing the cost.

Engineering Relationship in Group Management

Disregarding certain financial aspects, the main value of grouping a number of small mills under a common management is the fact that as a part of such an organization each mill can secure better financial and executive brains than would be the case were it acting alone—this purely on a price basis. The addition of engineering brain to this reason for mergers would tend rather to strengthen it.

Going back to the factor comprising management's responsibility—the purchase of cotton, the sale of goods, and the manufacture of these goods—it is to be noted that from a dollar-and-cents point of view, manufacture is the least important item.

This year cotton has sold from a low of 22 cents to a high of 31.50 cents. Assuming two mills, A and B, each with the same manufacturing costs (10 cents per lb.) and the same waste figure (15 per cent), both making the same commodity but with the difference that A buys cotton at 22 cents while B goes in the market at 31.50 cents, we have:

	A	B
Cotton	22 cents	31.50 cents
Clean, i.e., shrunk 15 per cent for waste	25.88 cents	37.06 cents
Manufacturing cost	10 cents	10 cents
Total mill cost per lb.	35.88 cents	47.06 cents

By clever buying, A's total cost is 11.7 cents per pound lower than what B has to pay, and this difference is 17 per cent greater than the entire cost of manufacturing. Is it any wonder that mill treasurers seem unaccountably deaf to a proposition involving an expensive installation which will cut the costs as much as one cent per pound?

For reasons of overhead and burden, a mill sold full over a long period of time shows a greater profit than one not so well sold but more efficiently operated, though the ratio is not so great as in the case of cotton buying. These facts are brought out not to minimize the importance of manufacture, and with it the value of engineering, but to establish the relative values of the other items of management. It is unfortunately true that neither the trading (cotton) profits nor those due to merchandising can be foretold. On the other hand, the value of any engineering idea applied to production can be accurately predetermined, and in the long run highly efficient production will show steady gains, while cotton buying and merchandising must, because of the law of averages, show occasional losses.

Engineering Organization for Production. In group organizations, the various factors requiring executive effort are made manifest through departments. For example, production is centered in one department. The information necessary for executive action is accumulated by means of records, and the control concentrated on such items as vary from a normal or standard. This idea applied to engineering would indicate in a group organization the office of a chief engineer with a subordinate force for records, etc. The fact that this office is practically non-existent is probably because of the subordinate position of manufacturing as compared with other management problems. It is true, however, that management needs definite engineering knowledge in the control of its mills, and admitting this fact, the question would seem to be one of method.

It might be feasible to require in the production department additional reports covering the functions of the mechanical engineer in the mill, these reports to be drawn up by the "engineer" rather than by the "manager." Such reports as would indicate the kilowatt-hours or horsepower-hours per pound of fuel; condition of the boilers as to scale, etc.; the friction load in the plant; reports on lighting based on foot-candle meter readings; and the regular reports covering production, machine speeds, settings, efficiencies, etc., which in the broad sense of the word are engineering functions, would, it is believed, cover this field. The working out of normal or standard values throughout the mill on the points covered by these reports (also an engineering function) would serve to fix certain standards of performance required from the mill. Variation from these standards would be the subject of an engineering investigation. Such a method presupposes the employment of an engineering firm on a retainer basis and also that the organization as outlined would be so complete as to require but little time for the engineer to cover the routine work. Special engineering work developed from this plan could be made the subject of a report to the treasurer and action in each case taken as might seem best. It is interesting that this idea as outlined to an engineer was rejected as valueless on the grounds, hardest to argue, that it had been tried and failed.

It is well to note, however, that the need for this type of work exists and that the methods which will give the best results are distinctly up to the mechanical engineer.

Some Examples of Engineering in Textile Mills

Granting the arguments so far made, it appears that there should be a distinct place for mechanical engineering in management, and that management is far from using the engineer to his full value. This would seem to be primarily a matter of education.

Some years ago an engineer visiting a mill found the following conditions: The mill was heated by the exhaust steam, heat being required for five months out of the twelve. The other seven months the exhaust wasted into the air. Furthermore, when steam was cut in on the heating system an additional back pressure was developed of from three to four pounds. This looked like a clear case to the engineer, who reported in detail to the owners, recommending a condenser for the engine and that live steam be used in heating. He showed an appreciable saving and his figures were undoubtedly correct. Although the owners were progressive and up to date, the engineer's recommendations were disapproved.

This is the other side of the shield. The agent and the plant

(*Continued on page 359*)

The Sine Bar as a Universal Planing Gage

Details of an Accurate System of Gaging for Use Where Large Pieces Are Machined at Comparatively Long Intervals—Use of Sine Bar as a Templet for Setting Planer Head and Tools—Formulas

By R. H. RAUSCH,[1] PLAINFIELD, N. J.

THE object of this paper is to describe a universal system of gaging for angular machined parts that is particularly applicable to planer work and involves the use of the sine bar and distance pieces. This system was developed in a plant manufacturing large machine tools where the gages for the large machines were used only at comparatively long intervals.

Since the design of these machines is changed from time to time and since it is difficult to make the large gages required with precision, the cost is considerable. By referring to Fig. 1 the difficulties of using large gages will be appreciated—they are so large that it requires two men to handle them and there is no such thing as a sense of "feel." Such gages must always be held at the same points so that the deflection due to the weight of the gage will always be the same. On account of the weight the gages had to be made comparatively narrow, and it required considerable skill to determine when the gage was square with the work and not binding the feeler paper on one corner.

Another disadvantage of this system was that all these large gages had to be handled and stored very carefully, even after the design of the particular machine had become obsolete, in order to take care of repairs to existing machines. Unless these gages are handled and stored very carefully they are apt to become bent so that their accuracy is destroyed. A much more accurate method of gaging is to make the gage wide and heavy enough so that there is no question about its being placed square with the work, and so that there is no danger of its becoming distorted in handling and storing.

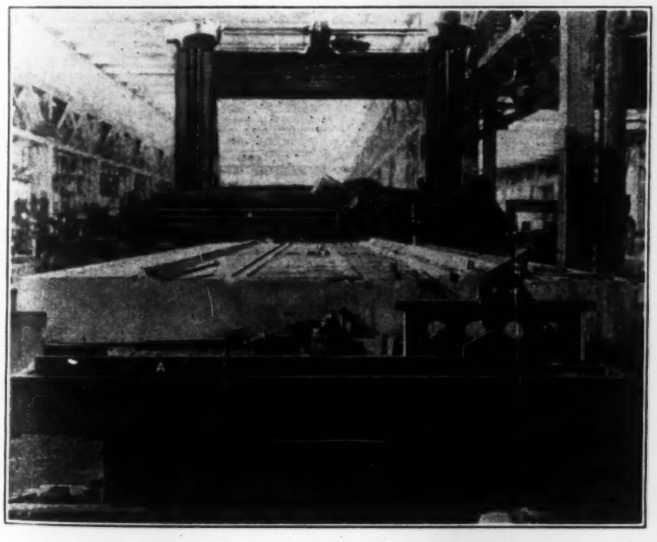

FIG. 1 VIEW OF PLANER MACHINING A LARGE PIECE, SHOWING OLD TYPE OF GAGE (*A*) AND SINE-BAR GAGE (*B*)

(The old type of gage required two men to handle it and had always to be held at the same points so that the deflection due to its weight would be always the same.)

Such a gage requires the use of a crane at frequent intervals to lift it on and off the work, and for that reason is more or less objectionable. It also takes considerable room to store such large gages.

THE SINE-BAR GAGE

In order to overcome these difficulties, the sine-bar gage shown in Fig. 2 was developed. The various sine bars used are shown in Fig. 3. The bar *BB* rotates about the center *O* on the pin *P*. By placing gage blocks *G* of the proper height under the pin *N*, the bar is moved through the desired angle and then clamped securely in place by the knurled nut *Y* as shown in Fig. 4.

By referring to Fig. 2, it will be observed that the sine bar is free to move on a parallel *T* placed square with the table. A movable stop *S* may be clamped on the parallel at any desired point. If

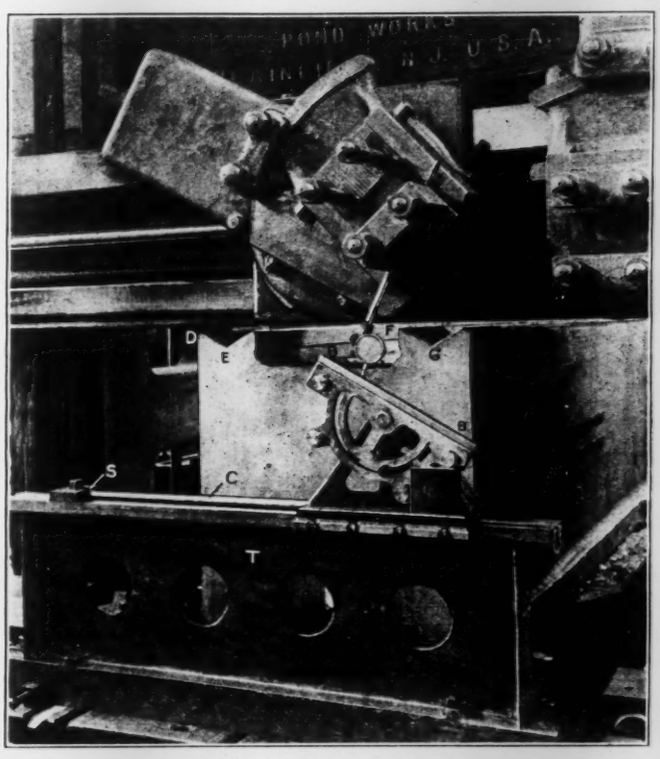

FIG. 2 THE SINE-BAR GAGE

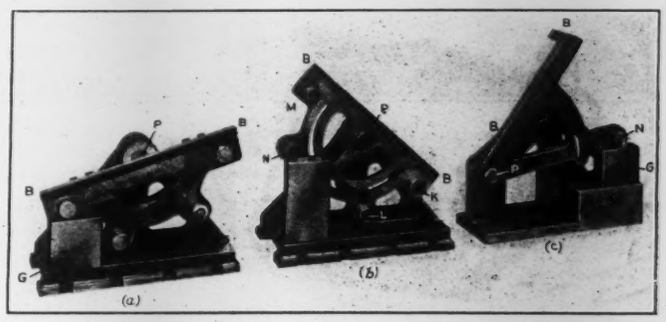

FIG. 3 THE VARIOUS SINE BARS USED

the sine bar is now moved up against the stop *S* and subsequently a gage bar *C* of any desired length is put between the stop and the sine bar, two gage surfaces for comparison with the work will be provided, each having any desired angle with the horizontal and at any distance apart.

The method of comparing the gage surfaces with the work is shown in Fig. 2. An indicator is clamped by the tool strap of the planer head and the head swiveled so that when the indicator is run along the surface *BB*, the indicator remains at zero. By running the table ahead and traversing the indicator over the surface *FG*, the error in the angle will be shown by the indicator in thousandths of an inch. A gage bar *C* having the required length is now placed in a vee planed in the top of the parallel *T* and the ad-

[1] Shop Supt., Niles-Bement-Pond Co. Mem. A.S.M.E.

Contributed by the Machine Shop Division and presented at the Spring Meeting, Cleveland, Ohio, May 26 to 29, 1924, of THE AMERICAN SOCIETY OF MECHANICAL ENGINEERS. All papers are subject to revision.

justable stop S brought up against it and clamped. The gage C is then removed and the sine bar moved over against the stop.

The planer head is then traversed across the table and, with the sine bar set to the required angle, the head is swiveled until the indicator remains at zero when traversed down the surface BB. If the planer table is now advanced and the indicator traversed across the surface DE, the error in the distance between the angular surfaces will be indicated by the plus or minus reading of the indicator and the error in the angle by the change in the reading as the indicator traverses down.

It will be observed that with any given height of parallel T (see Fig. 2), work varying considerably in height may be satisfactorily gaged.

When the angles which DE and FG make with the horizontal are equal, the length of the gage C will be equal to the horizontal distance between D and F. When the angles are not equal, the length of the gage is dependent on the height of the parallel on which the sine bar slides with respect to the work, the perpendicular distance from the center of the pin P to the bar BB, the two angles, and the horizontal distance between the two surfaces at some given point.

It will be shown later that the formulas for the length gage may be simplified materially if the sine bar is constructed so that the bar BB goes through the center line of the pin P as shown at (a), Fig. 3. If in addition the parallel on which the sine bar slides is made adjustable in height and the center of the pin P is brought to the horizontal plane where the measurements are taken, the length of the gage will be equal to the horizontal distance between the two angular surfaces and no calculations will be required. This may easily be done in practice by first bringing the bar BB to a horizontal position by using a gage block G of proper height and then adjusting the height of the parallel so that when the indicator in the planer head is run over the horizontal surface from which the measurements are to be taken and then over the surface BB the indicator will remain at zero.

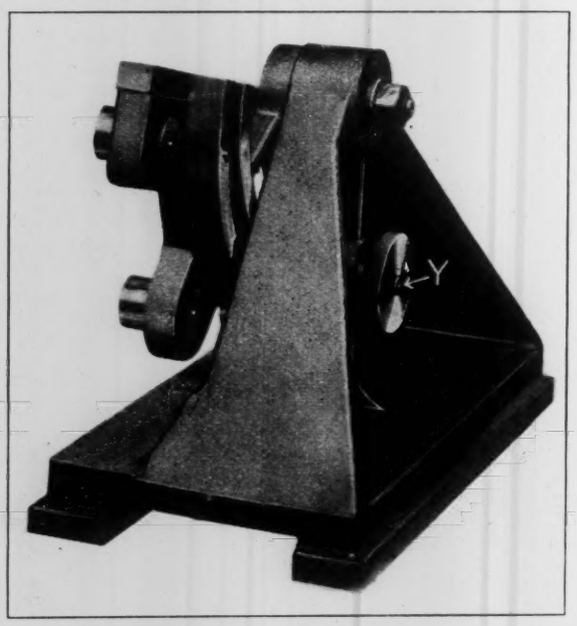

FIG. 4 VIEW OF SINE BAR SHOWING KNURLED NUT Y FOR CLAMPING BAR SECURELY IN PLACE

FIG. 5 SET OF PRECISION GAGE BLOCKS FOR MAKING MEASUREMENTS BY INCREMENTS OF 0.0001 IN.

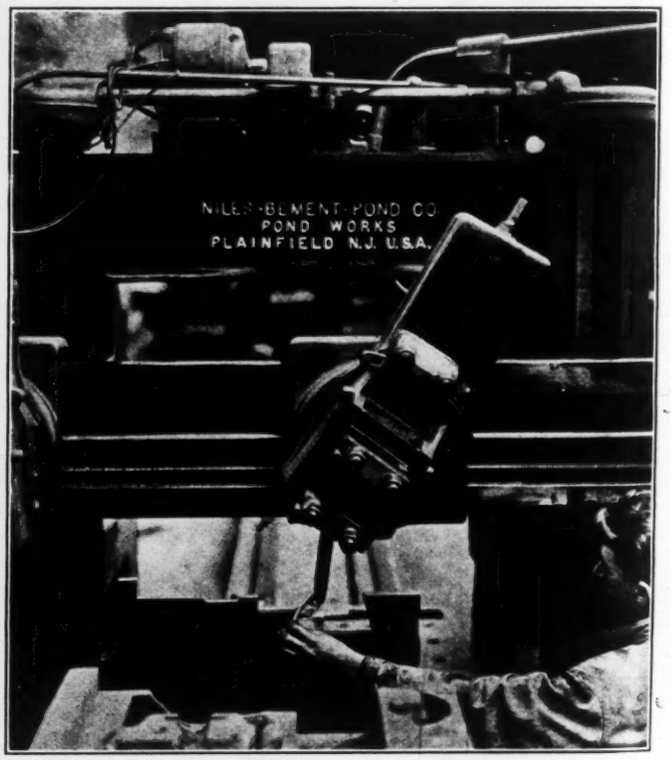

FIG. 7 SETTING PLANER TOOL WITH AID OF TEMPLET AND FEELER BLOCK

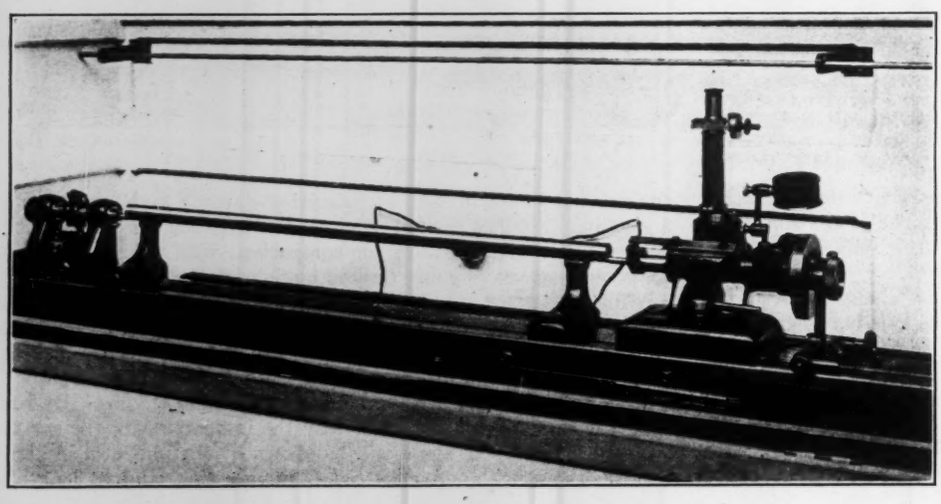

FIG. 6 MEASURING THE LENGTH GAGE C SHOWN IN FIG. 2

USE OF PRECISION GAGE BLOCKS

As stated before, gage blocks have been provided for the sine bar for the angles ordinarily used. However, when angles other than standard are required the set of precision gage blocks shown in Fig. 5 is used.

With these blocks measurements by increments of 0.0001 in. may be made. By increasing the radius from this pin P to the center of the measuring pin K [Fig. 3 (b)], the angle may be gotten to almost any desired degree of accuracy.

The length gage C shown in Fig. 2 rests in a vee planed in the parallel T. This length gage is made in the form of a tube with hardened and ground steel plugs in the end. These gages are ground and lapped to the proper dimension as determined on the Pratt & Whitney measuring machine as shown in Fig. 6.

These gages may be made adjustable in length by having one end

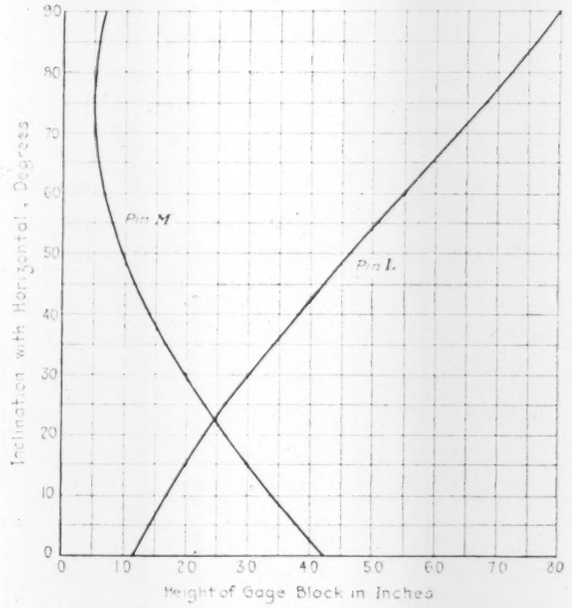

FIG. 8 HEIGHTS OF GAGE BLOCKS FOR SINE BAR SHOWN IN FIG. 10

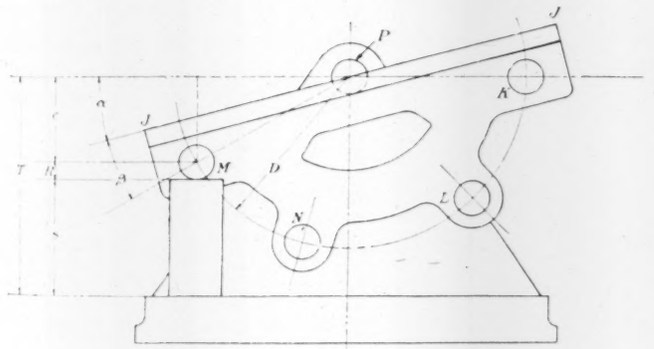

FIG. 9

$C/D = \sin(\alpha + \beta)$; $C = D \sin(\alpha + \beta)$
$S = T - R - C = T - R - D \sin(\alpha + \beta)$

of the gage telescope in the other. For standard lengths it seems best to use the non-adjustable type.

USE OF SINE-BAR GAGE AS TEMPLET

It is fairly common practice to provide templets such as the one shown in Fig. 7 to help the operator to set up and do his work without unnecessary delay in laying out. In the same way the sine bar has been used to advantage as a templet in setting the tools. It is customary to use a hardened feeler block between the tool and the gage as shown in Fig. 7, where a templet is employed, so that the tool will not mar the gage.

The operator in setting the heads for planing the surfaces FG and DE, Fig. 2, sets the head from the sine bar. Since this is the case the angle will be correct, even if the crossrail is not set parallel with the table.

ACCURACY

By referring to Fig 3(b), it will be noted that two sets of pins K, M and L, N have been provided for use in connection with the gage

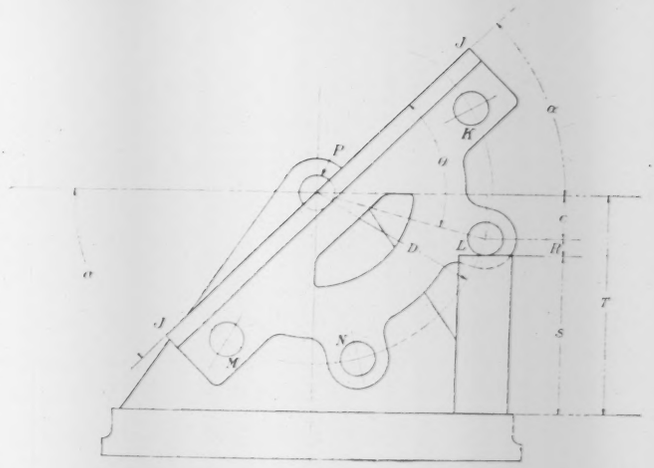

FIG. 10

$C/D = \sin(\theta - \alpha)$; $C = D \sin(\theta - \alpha)$
$S = T - R - C = T - R - D \sin(\theta - \alpha)$

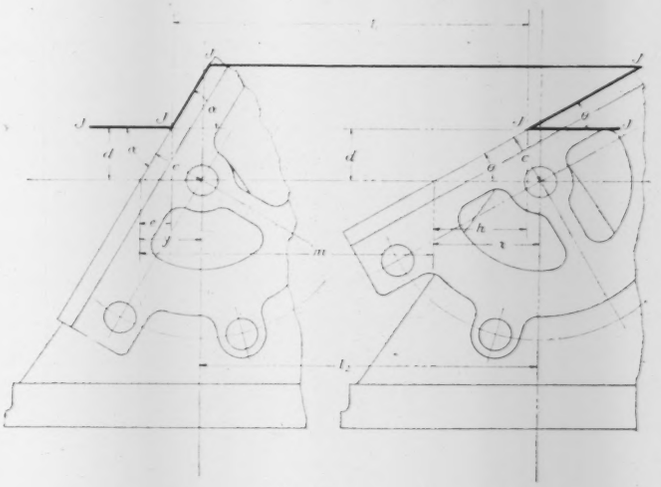

FIG. 11

$l_2 = M + x - y$; $x = c \operatorname{cosec} \theta$; $y = c \operatorname{cosec} \alpha$
$M = l_1 + e - h$; $e = d \cot \alpha$; $h = d \cot \theta$
$M = l_1 + d \cot \alpha - d \cot \theta$
$l_2 = l_1 + d(\cot \alpha - \cot \theta) + c(\operatorname{cosec} \theta - \operatorname{cosec} \alpha)$
When $c = 0$, $l_2 = l_1 + d(\cot \alpha - \cot \theta)$
When $\alpha = \theta$, $l_2 = l_1$

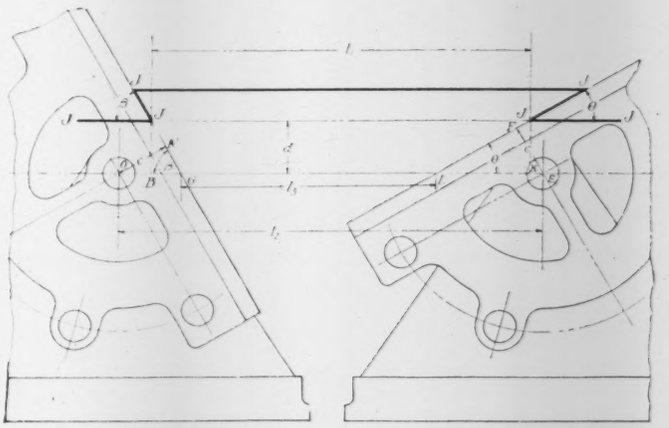

FIG. 12

$l_2 = l_3 + OG + LE$; $l_3 = l_1 - BG - LK$
$BG = d \cot \beta$; $LK = d \cot \theta$
$l_3 = l_1 - d(\cot \beta + \cot \theta)$
$OG = c \operatorname{cosec} \beta$; $LE = c \operatorname{cosec} \theta$
$l_2 = l_1 - d(\cot \beta + \cot \theta) + c(\operatorname{cosec} \beta + \operatorname{cosec} \theta)$
When $c = 0$, $l_2 = l_1 - d(\cot \beta + \cot \theta)$
When $c = 0$ and $d = 0$, $l_2 = l_1$
When $\theta = \beta$ and $c = 0$, $l_2 = l_1 - 2d \cot \theta$

blocks. It will also be noted that any error in the height of the gage block G will produce less error in angle when placed under N than when placed under M. In other words, the best obtainable accuracy is secured when measurements are taken with the pins N and P in the horizontal line, the accuracy decreasing as N moves from the

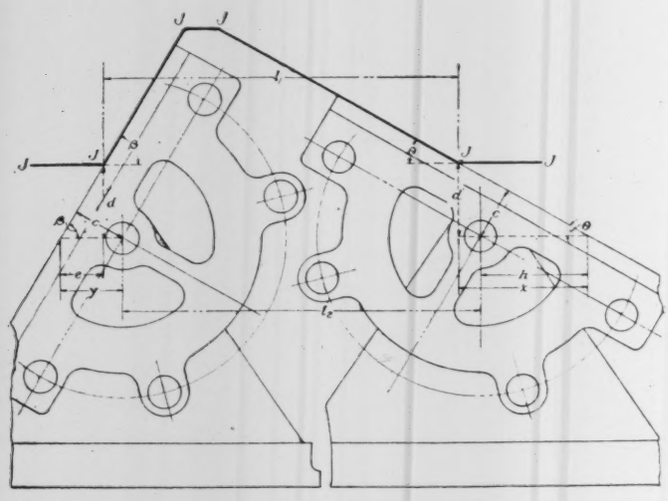

FIG. 13

$l_1 + x + e = l_2 + h + y$

$l_2 = l_1 + x + e - h - y$

$x = d \cot \theta$; $e = d \cot \beta$; $h = c \operatorname{cosec} \theta$; $y = c \operatorname{cosec} \beta$

$l_2 = l_1 + d \cot \theta + d \cot \beta - c \operatorname{cosec} \theta - c \operatorname{cosec} \beta$

$= l_1 + d(\cot \theta + \cot \beta) - c (\operatorname{cosec} \theta + \operatorname{cosec} \beta)$

When $c = 0$, $l_2 = l_1 + d (\cot \theta + \cot \beta)$

When $c = 0$ and $\theta = \beta$, $l_2 = l_1 + 2 d \cot \theta$

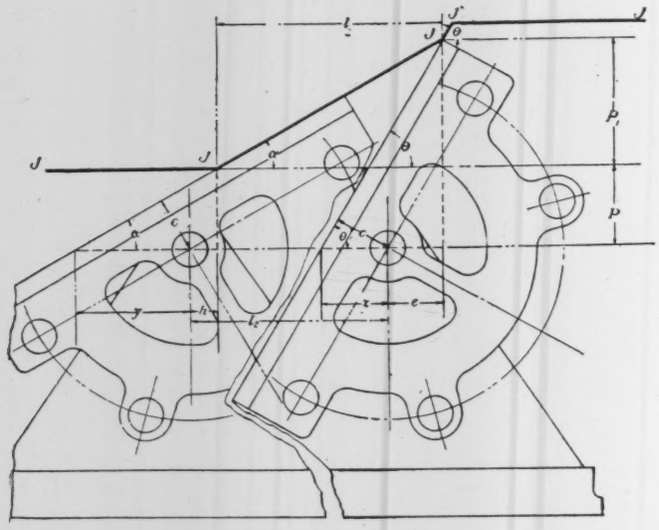

FIG. 14

$l_2 = l_1 + h - e$; $\dfrac{y + h}{p} = \cot \alpha$

$h = p \cot \alpha - y$; $y = c \operatorname{cosec} \alpha$

$h = p \cot \alpha - c \operatorname{cosec} \alpha$

$\dfrac{e + x}{p + p_1} = \cot \theta$; $e = (p + p_1) \cot \theta - x$

$x = c \operatorname{cosec} \theta$; $e = (p + p_1) \cot \theta - c \operatorname{cosec} \theta$

$l_2 = l_1 + p \cot \alpha - c \operatorname{cosec} \alpha - (p + p_1) \cot \theta + c \operatorname{cosec} \theta$

When $c = 0$, $l_2 = l_1 + p \cot \alpha - (p + p_1) \cot \theta$

horizontal. In the sine bar shown in this figure, pin M is used for angles from 0 deg. to 15 deg. and pin N for angles from 15 deg. to 90 deg.

Figs. 9 and 10 show the height of gage blocks needed for angles from 0 deg. to 90 deg. when both pins M and L are used. By referring to Fig. 8, it will be observed that in this instance the slope of the two curves is the same at 15 deg., or in other words, either pin may be used with an equal degree of accuracy. When the angle with the horizontal is less than 15 deg. pin M will be used, and when greater than 15 deg., pin L. The accuracy obtainable for these gages is of course dependent on the accuracy with which the gage is made, since the sense of "feel" has been eliminated by the use of the indicator. Gage blocks may be obtained which are correct to a few millionths of an inch, as certified by the Bureau of Standards. The hardened, ground, and lapped pins have been made with the same limits of accuracy obtained on accurate plug gages. The distance from the center of the pin P to the base from which the measurements are taken was obtained by scraping the base to a gage. The length of the distance gage may be read on the P. & W. measuring machine to 0.00001 in.

From the foregoing it will be seen that for ordinary machine-shop work the gage is amply accurate.

FORMULAS

The formulas for the height of the gage blocks required and the length of the distance gages are simple to develop and are included here mainly for the convenience of any who may care to make and use this type of gage. See Figs. 9–15.

The surface $JJJJ$ is the surface to be gaged in every case. The advantage of having the surface of the bar pass through the center of the pin about which it rotates will be apparent from these formulas. Fig. 15 shows a method that may be employed in laying out or gaging the distance from a planed angular surface to a bored hole.

CONCLUSIONS

The following conclusions in regard to the usefulness of the sine-bar gage have been arrived at by the author after about two years' use.

1 It provides a means of accurately gaging large planer work,

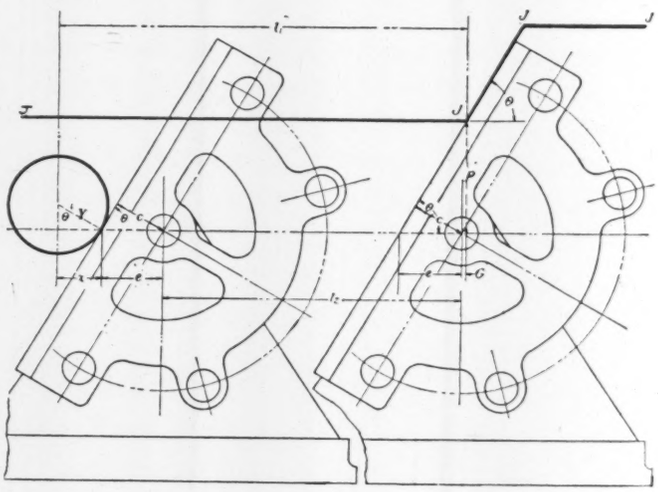

FIG. 15

$l_2 = l_1 - x - e - g$; $x = Y \sin \theta$

$\dfrac{e + g}{p} = \cot \theta$; $g = p \cot \theta - e$

$l_2 = l_1 - Y \sin \theta - p \cot \theta$

showing the errors in angle and center distance and eliminating any errors due to sense of "feel."

2 For jobbing work or where large pieces are machined only at long intervals of time, it eliminates the necessity for making and storing expensive gages.

3 The use of the sine bar as a templet for setting the tools is a distinct advantage in laying out work on the planer.

4 It makes possible the setting of the planer head to an exact angle very quickly, and renders it unnecessary for the operator to run over the work several times, swiveling the head until the work matches the gage. In other words, it eliminates the cut-and-try method of setting planer heads.

5 The sine bar is not recommended in the case where small work is made on a quantity-production basis, for it takes longer to gage work with the sine bar than it does with the usual type of planing gage. The cost of the gages for work on a quantity-production basis is also not as important as when parts are machined relatively infrequently.

SURVEY OF ENGINEERING PROGRESS

A Review of Attainment in Mechanical Engineering and Related Fields

Heat-Transfer Symposium

A GROUP of papers dealing with various aspects of the important subject of heat transfer were presented before the Division of Industrial and Engineering Chemistry of the American Chemical Society at the meeting of the society held in Washington, D. C., April 21 to 26. Abstracts of most of the papers forming this symposium are given below.

Heat Transfer from Bare and Insulated Pipes

DATA are given for the heat loss from 1-in., 3-in. and 10-in. bare steam pipe carried out at the Mellon Institute with the idea that more reliable data could be secured by testing pipes of various sizes under the same conditions than by comparing the results of other investigators on pipes of various sizes under different conditions.

The electrical method of testing was used in this investigation. When conducting tests on bare pipes it is very desirable that the room temperature remain constant throughout the work, for the rate of heat loss is dependent upon the absolute temperature as well as upon the temperature difference. The 1-in. pipe was selected for test at the higher temperature, as the relatively small amount of heat loss from a 1-in. pipe could not greatly affect the room temperature. This pipe was run up to a temperature of 800 deg. fahr. The average room temperature throughout this test was 81 deg. fahr., and the temperature did not vary more than 1.8 deg. fahr. during its progress. The 3-in. pipe was run up to a temperature of 760 deg. fahr. and the 10-in. pipe to a temperature of 472 deg. fahr.

From these tests were derived experimental curves shown in the original paper and empirical equations to express these curves. In addition to this a table is given showing the loss in dollars and cents and in pounds of coal per 100 lineal ft. of bare iron pipe for temperatures up to 664 deg. fahr. For bare pipe this loss varies from $1.32 per 100 lineal ft. of 0.5-in. pipe at 180 deg. fahr., to $297.50 per 100 lineal ft. of 18-in. pipe at 664 deg. fahr. Another table shows heat losses from horizontal bare iron pipes 0.5 to 18 in. in diameter for temperature differences of 50 deg. to 800 deg. fahr.

The thermal conductivity of pipe coverings is discussed next. The term "thermal conductivity" of a material is defined as the number of heat units transferred by conduction per unit area across unit thickness per degree difference of temperature between the faces, the direction of heat flow being perpendicular to these faces. In terms of the units generally used in power-plant practice this is equivalent to the heat transmitted in B.t.u. per hour through 1 sq. ft. of material 1 in. thick and having 1 deg. fahr. temperature difference between its faces.

It is practically impossible to realize a condition in engineering or laboratory practice where the temperature difference between two faces 1 in. apart is only 1 deg., and the conductivity of an insulating material has therefore generally been taken as the average conductivity value through the whole test section. The conductivity thus obtained is plotted against the temperature difference between the two surfaces or between the inner surface and the room temperature. Plotting average conductivity against temperature difference at the two surfaces for heat-insulating materials may give in some cases, where single thicknesses are used, results sufficiently accurate for engineering purposes; but where compound sections are used, and where different external surfaces exist, as in coverings on various-diameter pipes with a resulting change in the surface emissivity factor, it is not at all safe to use the values obtained from conductivity curves plotted against temperature difference. For instance, it is a well-known fact that the conductivity of heat-insulating materials increases as the temperature increases. The conductivity value of a given material whose faces are at 200 deg. and 100 deg. fahr. must therefore be lower than the conductivity for the same material having its faces at 700 deg. and 600 deg. fahr., although the temperature difference is 100 deg. in each case.

In all tests on commercial insulating coverings conducted during the investigation reported in this paper, there was no covering tested the conductivity of which did not not obey a straight-line law. This fact reduces considerably the experimental work required to obtain true conductivity values for the insulating materials tested, as it is only necessary to measure the heat transmitted through the covering and the corresponding surface temperatures. Accordingly, it has been assumed that it is perfectly safe to use the equivalent conductivity values obtained in this work as the true value of thermal conductivity for the coverings tested.

The results obtained on a number of materials are plotted in the form of curves, all being straight lines. The effect of voids in the relation to the thermal conductivity of pipe coverings involving the porosity of these coverings is discussed next, and methods for determining the apparent density and porosity are described.

From data obtained in these tests it would appear that the thermal conductivity of a material does not depend upon the porosity of the material alone. In some types of material the transfer of heat takes place mainly by conduction, while in other types the transfer results mainly from radiation and convection. Since the radiation loss is proportional to the difference of the fourth powers of the absolute temperatures, it is to be expected that a covering in which the heat flow takes place mainly by radiation will show a very steep conductivity curve. The increase in heat loss due to internal convection currents will also tend to cause the conductivity curve to be steeper than for conduction only.

From various considerations the author arrives at the conclusion that the conductivity curve depends probably to a great extent upon the size of the air pockets.

The nature of the material in the covering also affects the thermal conductivity. Some substances are composed of a highly reflecting medium which tends to reflect the heat back into the covering, thus more readily preventing its escape. The shape of the air pockets probably has some effect upon the conductivity of the covering. No general law has, however, been derived, as investigation showed that the variables are too numerous and too complicated to permit of applying even an empirical equation to the findings.

Heat losses from canvas surfaces of pipe coverings are discussed next. For this purpose canvas-surface-loss equations have been derived for use by engineers who wish to determine the approximate heat loss for pipe covering already in service and without interruption of the steam service, and instructions are given for calculating these losses. Also the subject of calculating heat losses through coverings is extensively discussed. This part is not suitable for abstracting. (R. H. Heilman, Mem. A.S.M.E., Mellon Inst. of Industrial Research, Pittsburgh, Pa., in *Industrial and Engineering Chemistry*, vol. 16, no. 5, May, 1924, pp. 451–458, 10 figs., *e*)

Heat Transmission in an Inclined Rapid-Circulation-Type Vacuum Evaporator

IN THIS case water was distilled under vacuum in an experimental evaporator with low-pressure steam condensing outside 3-in. tubes inclined at an angle of 45 deg. In this evaporator the liquor enters the top of the liquid space, boils up through the tubes, strikes a baffle plate in the vapor body, and returns through the downtake. At first an attempt was made to remove non-condensable gases from the steam chest through the wet-vacuum pump,

but this proved unsatisfactory. Better and more consistent results were obtained by carefully venting the steam chest directly into the vapor body. This method of venting causes a slight increase in the heat transmission, but this is assumed to be well within the experimental error of the tests as a whole.

Tests were made with variable steam pressure but without regulation of the vacuum and with steam entering either at the bottom or at the top of the steam chest. Another set of tests were made at a temperature level of approximately 140 deg. fahr. with varying steam pressure and steam entering the top of the steam chest. Contrary to expectations it was found that the heat-transmission coefficient varied greatly with the temperature difference. At a constant boiling temperature of about 142 deg. fahr. the overall coefficient of heat transfer increased from 465 to 1140 B.t.u. per hour per sq. ft. per deg. fahr. as the overall temperature difference increased from 42 to 81 deg. fahr. (D. J. Van Marle, Buffalo Foundry & Machine Co., Buffalo, N. Y., in *Industrial and Engineering Chemistry*, vol. 16, no. 5, May, 1924, pp. 458–459, 2 figs., *e*)

Forced Convection of Heat in Gases and Liquids

THE author tries to develop a more general expression for the film thickness in forced convection, and claims that this expression appears to correlate satisfactorily the available data on convection in both gases and liquids.

The film theory naturally leads to a relation between skin friction and heat transfer which makes it possible to calculate the forced convection from the available data on surface friction. A study of the problem from this point of view is made which seems to throw considerable new light on the complex problem of turbulent fluid motion.

The author derives from dimensional considerations a heat-transfer equation similar to that of Boussinesq and others, the three experimental constants for this equation being obtained by plotting recalculated data of certain observers who used both gases and water. From analogy between heat transfer and fluid friction he derives the Reynolds equation but from a new point of view, and by substituting Lees' equation for the resistance to flow in smooth pipes in this equation and making certain assumptions, he obtains an equation for gases and liquids which takes into account the variation of the resistance with a degree of turbulence and therefore should be applicable over the entire range above the critical velocity. He derives expressions for the heat transfer in the case of ideal gases and air and then somewhat similar equations for heat transfer for ideal gases and air with rough pipes and large smooth surfaces. The paper includes discussion and calculations regarding the variations in the character of the fluid motion at various points in the cross-section and the effect of such variations upon heat transfer. (Chester W. Rice, General Electric Co., Schenectady, N. Y., in *Industrial and Engineering Chemistry*, vol. 16, no. 5, May, 1924, pp. 460–467, 4 figs., *t*)

Optimum Operating Conditions for Pipe Heating and Cooling Equipment

IT HAS long been known that when fluids are flowing in turbulent motion high velocity gives good heat transfer and therefore reduces equipment expense, but causes excessive friction and therefore undue power consumption. Excessively low velocity reverses these conditions. For these reasons in designing heat-transfer equipment a fluid velocity should be chosen that will secure a proper economic balance between installation and operating costs. The first purpose of this paper is to develop a simple method of determining the proper velocity of flow to employ in any given case.

The authors express the optimum velocity by a somewhat complicated formula and it is found that this optimum velocity is independent of the temperature difference and a certain numerical coefficient α which enters into the expressing of film coefficient of heat transfer between inner wall of the pipe and the fluid inside the pipe, namely, $h = \alpha u^{0.8}$, where u is the linear velocity of fluid in ft. per sec.

If these quantities are high, the heat transfer is rapid and correspondingly cheap, but the relative influences of the factors affecting cost remain unchanged. Similarly, the viscosity is not a factor, except for its slight influence on the coefficient of fluid friction f. In other words, the optimum linear velocity for a viscous oil is almost the same as that for water, provided both flow in turbulent motion.

This formula is derived on the assumption that the major thermal resistance is due to the liquid film inside the pipe.

After having determined the proper velocity to employ in pipe heat-transfer equipment the authors proceed to the calculation of the size of equipment necessary to heat or cool a fluid to any required temperature by the use of a given medium. In particular they point out that when recovering waste heat one should determine how much of the available heat is worth recovering and limit the heat-exchange equipment to a corresponding size.

Formulas are derived for computing the optimum temperature of the heat exchanger for several cases, such as condensing a pure saturated vapor, cooling one fluid by another by countercurrent flow, preheating cold fluid, etc. (W. K. Lewis, J. T. Ward and E. Voss, Mass. Inst. of Technology, in *Industrial and Engineering Chemistry*, vol. 16, no. 5, May, 1924, pp. 467–468, *tp*)

Characteristics of Air-Blast Heaters

AFTER giving a brief description various types of heaters (including return-bend and miter types), this paper submits curves based on numerous tests of heaters in which air is preheated by being blown at right angles to the outside of staggered pipes within which saturated steam is condensing.

Heat transmission in blast coils appears to be dependent upon the depth of the heater—that is, number of rows of pipe that the air passes across; upon the rate of movement of the air across the pipes—that is, the weight of air heated per unit of time; the density of the air or gas passing across the pipes; the difference in temperature between the heating medium and the air and the amount of heating surface to free area. The nature of the material and the condition of its exterior surface through which the heat is transmitted have some effect upon transmission, but the film resistance between the air and the pipe surface is so great that other factors, internal film resistance and condition of exterior surface, have no great effect upon heater performance.

Pipe-coil-heater performance is usually presented as temperature rise for various rows at several velocities and steam temperatures. The paper gives a plot of typical heater performance characteristics and explains how such plots can be used. (F. R. Ellis and J. D. White of the B. F. Sturtevant Co., Hyde Park, Mass., in *Industrial and Engineering Chemistry*, vol. 16, no. 5, May, 1924, pp. 471–473, 8 figs., *dp*)

The Film Concept of Heat Transmission Applied to a Commercial Water Heater

THE "film concept" of heat transmission of fluids goes back to the year 1874 when Reynolds derived a theoretical equation for the coefficient of heat transfer between a fluid and a metal wall.

Fig. 1 represents an elementary section of a metal tube, upon one side of which steam at a temperature T_s is being condensed by reason of the cooling of the tube due to the flow of water at a temperature T and at a velocity of U on the other side of the wall of the tube of a thickness L. The resulting steam-side temperature is T_2 and the water-side temperature is T_3.

According to the film concept the flow of heat from the steam to the water is opposed by three resistances:

$R_s = \frac{1}{h_s}$ = resistance to flow of heat through film of condensation adhering to steam side of tube.....(1)

$R_t = \frac{1}{h_t}$ = resistance to flow of heat through wall of tube.....(2)

$R_w = \frac{1}{h_w}$ = resistance to flow of heat from wall of tube to main body of flowing water by reason of a relatively stationary film of water assumed to adhere to the water side of tubes.....(3)

The symbols h_s, h_t, and h_w represent the rates of heat transmission through the steam-side film, through the metal of the tube, and through the water-side film, respectively, in B.t.u. per degree temperature difference per hour per square foot of surface of the water side of the tube.

Basing calculations on a recent formula for the film coefficient of heat transfer from the inner wall of the tube to the water flowing past it, a formula is developed for expressing the film temperature in terms of the temperature of the main body of the water. As a result, it is possible to allow for the variation of the film coefficient throughout the heater. Assuming a reasonable value for the film coefficient on the steam side and allowing for the thermal resistance of the tube wall, the predicted number of square feet of heat-exchange surface is calculated for various sets of conditions for which test data were available. The predicted value of the heating surface was then compared with the actual value, and excellent agreement was obtained.

In a heater having clean tubes, when heating water flowing inside the tubes with steam at approximately atmospheric pressure outside of the tubes, the following determinations seem justifiable:

1 The instantaneous coefficient of heat transfer on the water

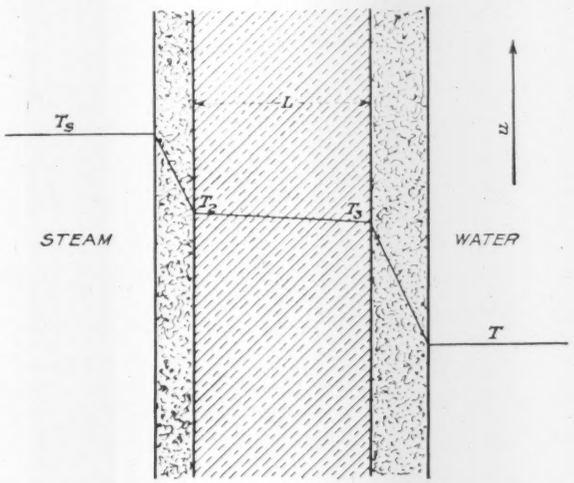

FIG. 1 ELEMENTARY SECTION OF A METAL TUBE OF A WATER HEATER USED TO ILLUSTRATE THE PRINCIPLE OF THE FILM CONCEPT

side at an elementary section of the heating surface may be calculated from an equation suggested by McAdams and Frost and given in the original article.

2 A constant coefficient of heat transfer on the steam side of 2100–2200 may be assumed.

3 The overall coefficient of heat transmission throughout the heater varies approximately according to a straight-line function of the water temperature, i.e., $h = n(m + T)$.

4 The amount of heating surface may be determined by a formula given in the original article. (D. K. Dean, Mem. A.S.M.E., Alberger Pump & Condenser Co., Boston, Mass., in *Industrial and Engineering Chemistry*, vol. 16, no. 5, May, 1924, pp. 479–438, 3 figs., 2 tables, *e*)

Loss of Heat from Furnace Walls

THIS paper is an attempt to emphasize the general more important well-known principles of heat transmission without concealing the incompleteness of data on certain facts, together with a description of an improved disk and guard-ring method of measuring thermal conductivity. This method, primarily developed by M. S. VanDusen of the U. S. Bureau of Standards, was compared with the box method of measuring thermal conductivity and it was found that the results obtained by both methods agree fairly closely, with certain advantages as to simplicity of calculations and measurement in favor of the disk method.

The results of thermal-conductivity measurements for a number of commercial insulators are given in a figure in the original article, where thermal conductivities are plotted against the temperature of the hot surface of the insulator, the cold-surface temperature being in all cases 65 to 70 deg. fahr.

As regards factors affecting thermal conductivity, temperature is the first to be mentioned as having an important effect. Refractories and insulators in general show a marked increase in conductivity with temperature, while magnesia brick is unique in showing a decrease.

Density is said to be perhaps the most important factor affecting the conductivity of thermal insulators and, fortunately, it may be controlled by proper selection of the raw materials of manufacture. In curves in the original paper the effect of density is shown by using powdered Sil-O-Cel packed to 10, 14 and 18 lb. per cu. ft., the chemical composition and other conditions being kept constant. A conspicuous feature of these graphs is the greater rate of increase of conductivity, with temperature, of the powder at the lower densities.

Finally, the effect of density is illustrated by the graphs in another figure, which show the conductivities of two Therm-O-Cel blocks of identical composition but of different densities. The data for an 85 per cent magnesia block are included for comparison.

That density alone does not determine the conductivity at a given temperature is evident from the fact that an 85 per cent magnesia block weighing 13 lb. per cu. ft. conducts more heat than a block of different composition weighing 16.9 lb. per cu. ft. Either the composition or the nature of the pore spaces makes this difference. In general, porosity due to fine pores is more effective in insulation at elevated temperatures than the same volume of larger pores.

As regards the influence of the size of pore space, it has been shown by Mellor that there is a particular temperature at which the quantity of heat traveling across the pore space by radiation equals that which would be carried by conduction by a solid in the same space.

The authors used these facts as a confirmation of the fallacy of attempting insulation in furnace walls by the use of so-called "dead air space." Besides the intense radiation through air at high temperatures, there is also rapid convection. Further, the average velocity of the molecules in air, at 1100 deg. fahr., is approximately 60 miles a minute (this calculation can be made from information to be found in many standard texts on physical chemistry); it might be well, therefore, to use the term "live air space" instead of "dead air space."

Finally, there is the thorough work of Ray and Kreisinger, of the Bureau of Mines, to show how readily radiant heat leaps across an air space at the temperature of furnace walls. With an air space between the firebrick lining of the furnace and the outer common brick wall, the bureau found that "the resistance of heat passage of the air space is very low compared with that of either wall, only about one-fourth as much."

The next factor discussed is elasticity of the insulator. The authors come to the conclusion that it seems certain that the thermal conductivity of certain insulators and refractories depends to some extent upon the firmness of the bonding and as a concomitant variable upon the firing temperature.

The subject of temperature gradients of composite walls is discussed next. These may be calculated by using the potential concept, namely, that the drop in potential or temperature is proportional to the thermal resistance per unit area, or to the length of material through which the heat passes, divided by the conductivity. On this basis the temperature gradient was calculated in the original paper for the wall of a commercial brick kiln of which the temperatures of the inside and outside wall surfaces were known. A figure in the paper shows also temperature gradients through a composite wall, the temperatures at the several points of which were determined experimentally by the use of calibrated thermocouples and a high-grade potentiometer.

Finally, the economics of heat insulation are discussed. The insulated wall loses only 40 per cent as much heat as the uninsulated wall. At a temperature of 1800 deg. fahr., for example, the losses are, respectively, 370,000 and 940,000 B.t.u. for each thousand square feet of wall surface. The saving, 570,000 B.t.u. an hour, represents a monetary saving of $2500 yearly. To insulate this 1000 sq. ft. of wall and save this $2500 a year would have required 3560 insulating brick of the kind used.

The saving due to the use of insulation varies with the temperature of the furnace. The variation with temperature may be seen

from Table 1. Again the cost of heat has been taken as 50 cents per million B.t.u.

TABLE 1 RELATION OF FURNACE TEMPERATURE TO NEED OF INSULATION

Furnace temperature, deg. fahr.	Heat Losses B.t.u. per sq. ft. per hr. Insulated wall	Uninsulated wall	Difference	Saved by insulation for every 281 sq. ft. of wall (or area covered by 1000 insulating brick laid 2.5 in. thick) Millions of B.t.u. a year	Dollars a year
900	153	357	204	502	251
1400	272	680	408	1005	502
1900	396	1002	606	1492	746
2400	520	1328	808	1990	995

A brief bibliography of the subject is appended to the original paper. (Robt. Calvert and Lyle Caldwell, Celite Co., Lompoc, Calif., in *Industrial and Engineering Chemistry*, vol. 16, no. 5, May, 1924, pp. 483–490, 10 figs., *te*)

A Heat-Transmission Meter

THE heat meter under discussion consists of a thin board of cork, or other material, about two feet square, and provided with thermocouples to indicate the drop of temperature occasioned by the flow of heat through it when placed against flat surfaces, such as floors, roofs, and the walls of buildings, tunnels, etc. When calibrated, the extent of the drop in temperature is a measure of the heat current. While this heat meter has certain possibilities in connection with laboratory work, its primary use is said to be in determining the rate of heat flow occurring under natural conditions.

An application of one of the meters to a 24-in. brick wall revealed a larger percentage variation in the heat current than was expected. A preliminary determination of the thermal conductivity of a 24-in. concrete wall under natural conditions gave a value of about 12 B.t.u. per sq. ft. per hr. per deg. fahr. per inch of thickness, as compared with the usually accepted value of 8.7 obtained from laboratory tests. The author believes that the conductivity of commercial walls will usually be found to be greater than that indicated by laboratory determinations, due to differences in density, moisture content, etc. (P. Nicholls, Research Laboratory, American Society of Heating and Ventilating Engineers, U. S. Bureau of Mines, Pittsburgh, Pa., in *Industrial and Engineering Chemistry*, vol. 16, no. 5, May, 1924, pp. 490–493, 5 figs., *d*. Compare Measuring Heat Transmission in Building Structures and a Heat Transmission Meter, P. Nicholls, in *The Journal of the American Society of Heating and Ventilating Engineers*, Jan., 1924, pp. 35–70, 30 figs. and abstracted in Mechanical Engineering, vol. 46, no. 5, May, 1924, pp. 289–291)

Heat Transfer in the Condensation of Water from Engine Exhaust Gas

THE work on which this paper is based was done at the request and with the support of the United States Army Air Service. It was occasioned largely by the proposed use of helium as a lifting gas in lighter-than-air craft.

There has always been a great waste of lifting gas in airships during extended flights, due to the necessity of maintaining static equilibrium by valving gas when the total load has been decreased by consumption of fuel. This waste might be tolerated when hydrogen is used, but must be nearly eliminated before a gas so rare and expensive as helium can be generally employed.

The problem, then, is that of maintaining a constant total load in order that change of load may not have to be compensated for by change of lift. To this end a survey of the possible means was made, and this resulted in the adoption of the method indicated in the title of this paper, namely, condensation of water from engine exhaust gas. The exhaust from a gasoline engine contains about 1.4 lb. of water per pound of fuel burned, and it is only necessary to sufficiently cool the exhaust products and separate and collect the condensed water.

Various cooling systems were considered, but the method finally adopted was that of direct air cooling by passing the exhaust gas through long, thin-walled pipes whose outer surfaces are exposed to the air flowing past the ship. (R. F. Kohr and L. Butler, Paper presented before the Washington Meeting, April, 1924, of the American Chemical Society. Not available in printed form at the time this abstract was prepared, *e*)

Heat Transfer in Small Pipes

THE heat-transfer rate under forced convection to water in a pipe $^1/_{16}$ in. in internal diameter and 10 in. in effective length was determined for various velocities. The pipe wall was heated by passing an electric current through it. The temperatures were measured by copper-constantan thermocouples soldered to the wall and placed in streams of liquid led off from holes in the tube. Transfer rates up to 8680 were obtained. These check well with the results given by Lewis and Walker. (F. C. Blake, Mem. A.S.M.E., E. I. DuPont de Nemours & Co., Wilmington, Del., and W. A. Peters, Jr., in a paper presented before the Washington Meeting, April, 1924, of the American Chemical Society. Not in print at the time this abstract was prepared, *e*)

Short Abstracts of the Month

ENGINEERING MATERIALS (See also Hydraulic Machinery)

Pearlitic Cast Iron

GENERAL discussion of the methods of production of this comparatively new material, with photomicrographs and structure of piston rings cast in pearlitic metal.

Lanz was the first in recent times to describe a method for producing pearlitic cast iron. That his process is the only one that can be used to produce this metal the present author denies. True, for thin-wall castings, such as cylinders of automobile engines, the Lanz process would have to be used, because thin walls cannot be cast from low-silicon metal and be good without some special after treatment. But in walls of medium and heavy thicknesses made up of low-silicon iron, good results may be obtained even without employing the Lanz process, provided the metal has been properly selected. The author attempts to prove this by photomicrographs, which unfortunately cannot be reproduced for mechanical reasons.

In general, one of the fundamental conditions for the formation of pearlite is that there should be silicon and manganese not in excess of 1 per cent, contents which usually tend to contribute to a slight graphitic formation.

On the other hand, the author does not agree with the recommendation made in another paper by Prof. O. Bauer to the effect that pearlitic iron should be rich in sulphur. Apart from the fact that low-sulphur cast iron is also deficient in gases and therefore has certain advantages, low-sulphur content does not in any way interfere with the formation of pearlite. In fact, the author cites an iron of so low a content of sulphur (0.032) that it cannot as a rule be obtained in a cupola, and in addition containing 1.90 silicon or about twice as much as Professor Bauer recommends for the proper building-up of pearlite.

This particular metal, it may be remarked, was made in a Wüst oil-fired furnace, which type of melting equipment has the advantage that iron produced in it, even when cast in thin walls, can be machined without any previous heat treatment even when its silicon content is as high as 1.9 per cent.

The author believes that pearlitic cast iron is particularly suitable for piston rings. Recent investigations leave no doubt as to the fact that piston rings with a pronounced ferritic texture stood up best in service, as the author proves by a comparison of analyses of four samples with the respective photomicrographs.

From this comparison it would actually appear that two rings—one pearlitic and the other ferritic—have stood up well in service, while two other rings—likewise one pearlitic and the other ferritic—showed rapid wear.

This would appear to prove that it is not correct to say that only pearlitic metal gives good service in piston rings, as ferritic iron can also give it. The question arises, therefore, why certain rings of both structures stand up well in service while others rapidly wear off.

As regards pearlite structure, this question is answered by saying that the result depends entirely on the manner of distribution of the graphite, the graphite in the samples that wore well being much finer than in those which gave poor service.

In the case of the ferritic-iron rings the graphite is found to be equally finely distributed in both of them, and in the author's opinion the difference in behavior under service conditions, while possibly due to metallurgical reasons, can be explained as purely mechanical; he ascribes the failure of one of the rings to the greater hardness of the cylinder in which the ring was used, which would mean that the results were due rather to improper test conditions than to differences in the metals themselves, although the author does not say so. (Director Karl Emmel in *Stahl und Eisen*, vol. 44, no. 13, Mar. 27, 1924, pp. 330–333, 11 figs., *de*)

FOUNDRY (See Engineering Materials)

HYDRAULIC MACHINERY

The Use of Glycerine in Hydraulic Machinery

GLYCERINE has been used quite extensively in hydraulic presses and similar machinery because it acts to a certain extent as a lubricant, preserves the flexibility of cup leathers, has a high viscosity which makes it less liable to leak through fine pores in castings and defects in joints, and, finally, freezes at a very low temperature. It is also found that in many instances glycerine acts as a protection against corrosion of metallic surfaces. There are, however, other instances where apparently it either induces or accelerates corrosion, and the purpose of the present investigation was to find out just what conditions govern the corrosion effects or inhibitions of glycerine.

Glycerine as such is a triatomic alcohol susceptible as are all alcohols of transformation into an acid under the action of an oxidizing agent. According to the investigations of Kaussmann, glycerine in contact with iron is always oxidized when atmospheric air is present. This transformation occurs in two successive stages. In the first, the oxygen taken from the air fixes a certain proportion of the hydrogen in the glycerine by forming water and converts the substance deprived of the hydrogen into aldehyde. In the second, the oxidizing action is exerted on the aldehyde and transforms it into glyceric acid.

Glyceric acid, in its turn, when in the nascent state forms on the metallic surfaces (iron) with which it comes in contact an extremely thin layer of glyceride of iron insoluble in the glyceric liquid, and the interposition of this film between the glycerine and the iron is sufficient to inhibit the further oxidation of the liquid. If glycerine fills the apparatus in which it is employed completely and no gaseous air is present, the oxidation of the substance in contact with the iron can proceed only as a result of the presence of air dissolved in the liquid. Because of this, transformation into aldehyde and subsequent conversion of the latter into an acid must necessarily proceed at a very slow rate, and is limited to a scarcely perceptible attack of the metallic surfaces bathed by the glycerine. If, however, the apparatus contains both glycerine and free air, the interposition between the iron and the liquid of an infinitely thin film of glyceride of iron immediately arrests oxidation. In both cases the metal immersed in glycerine is very well protected against corrosion.

If, however, in hydraulic apparatus glycerine comes in contact with metals other than iron, very different phenomena take place.

From an extensive investigation described in the original article it would appear that whenever two metals of different electrical potential are employed in hydraulic apparatus with glycerine as the working fluid the metal which constitutes the negative pole of the electric couple is always the one attacked.

Furthermore, the author claims to have established that the voltaic action is present in such cases at all times even when the glycerine is neutral but it does not become really strong until the glycerine becomes acidified. When this happens the electric action electrolyzes, at the same rate as it is being formed, the film of glyceride of iron which in one-metal apparatus inhibits acidification. The acid thus liberated forms at once a salt which the electric current redecomposes immediately as it is formed.

The alternative or simultaneous action of the acid and electric current which proceeds all the time at the expense of the metal parts is said to be sufficient to explain the grave character of the corrosion which is produced, but the above-described process is not the only one which is at work.

The flow of current through glycerine has the effect of producing an electrolysis of the liquid itself and hence accelerates its transformation. The oxidation of the glycerine which, without the presence of the electric current proceeds at an extremely slow rate and only superficially, becomes with the presence of the current and the consequent electrolysis far more rapid, and glyceric acid is transformed into oxalic acid. From this moment on, the attack of metallic parts becomes stronger and stronger, and it would appear that it does not reach its limit until the complete transformation of the glycerine.

It would furthermore appear that electrolysis during the various stages of oxidation which it produces in the glycerine generates in addition to glyceric and oxalic acids, a certain number of products of which we know comparatively little as yet. These products in acting upon each other appear to combine with the iron of the metallic salts (glycerates and oxalates) and produce a transfer of metal towards the positive pole of the electric couple.

The conclusion to which the author comes is that in hydraulic or hydropneumatic apparatus employing glycerine as a working fluid the parts should be so selected that under no condition could there be a contact of two different metals in the presence of the glycerine.

During the war in the hydraulic apparatus used on heavy guns where glycerine was employed as a working fluid there were many cases of corrosion due to the employment of parts of different metals. As there was no time to change the parts nitrogen was substituted for atmospheric air in the hydropneumatic apparatus. This was, of course, a purely emergency solution of the problem and cannot be recommended for industrial use. (Félix Mercier, Colonel of the Artillery, in *Revue Industrielle*, vol. 54, no. 2177, or New Series, no. 29, April, 1924, pp. 52–57, 4 figs., *p*)

INTERNAL-COMBUSTION ENGINEERING

North British Double-Acting Diesel Engine

THE North British Diesel Engine Works on the Clyde built a 2000-h.hp. double-acting two-cycle marine engine for a new motorship and it is said that the engine differs in certain respects from all other oil engines of similar specifications. Fig. 1 illustrates in a general manner the method of operation of this engine which is of the sliding-cylinder type. The arrangement is essentially that involving a pair of single-acting cylinders placed with the open ends facing one another and a single long-trunk piston working in both of them.

With the two-cycle method of operation the movement of the trunk in either direction will cause compression in either one or the other of the two cylinder ends so that the device is double-acting.

To transmit the reciprocating movement of the common trunk to the crank journals of the crankshaft the following arrangement is used. A gudgeon thrust transversely through the trunk carries bearings at its ends to which are attached side rods jointed near the crankpin bearing by means of a massive steel casting. This steel casting by the way straddles not only the end of the cylinder but also the cast-iron cross-girder on which the cylinder head rests and to which it transmits the load imposed on it by the gases under pressure.

There are good reasons why the cylinder is made sliding. This is done for the same reason which accounts for the use of cylindrical sleeves in the Knight gasoline engine. A movable cylinder liner with ports and working on stationary heads equipped with piston rings makes an effective valve arrangement giving large areas and quick openings and closings. Owing to the side connecting rods already mentioned and the space which must be left clear for them to move in, the accommodation of any valve gear other than that of the sliding sleeve would not offer any advantages. Even port scavenging, which requires an inlet belt as well as an exhaust belt, would be hard to squeeze in between the A-frames, side rods, and crosshead guides. The moving cylinder not only solves the air-

admission problem, but gives good scavenging. Since the air enters the cylinder at one end and has a clear sweep through to the exhaust ports, all the advantages of uniflow scavenging are consequently secured.

Contamination of the fresh air charge is minimized to an extent which cannot be so readily realized in any other construction except the opposite piston. Because of the low scavenging-air pressures which are made possible by the North British arrangement, work on the scavenging pump is reduced and running at unusually low speeds is made possible. By properly timing the sliding sleeve, the inlet ports are made to open just at the instant when the exhaust pressure has blown down and are held open for a short time after the piston

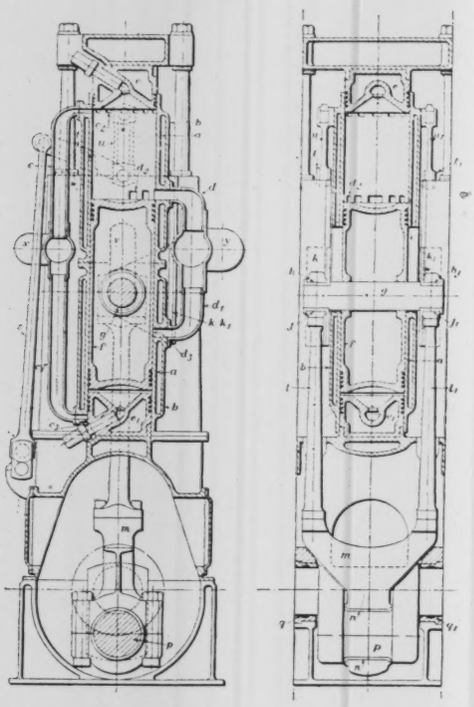

FIG. 1 DIAGRAM SHOWING METHOD OF OPERATION OF NORTH BRITISH SLIDING-CYLINDER ENGINE

has covered the closing edge of the exhaust ports. As a result, the scavenging pressure is allowed to build up in the cylinder before compression begins, a greater weight of air is therefore supplied to the cylinder before compression begins, a greater weight of air is therefore supplied to the cylinder, and greater amounts of fuel can be properly consumed.

As the bore and stroke dimensions of the engine are 24½ in. by 44 in., and as it develops 2000 b.hp. at 100 r.p.m. on a brake mean effective pressure of 63.7 lb. per sq. in., the success of the scavenging method appears substantial enough.

There are a number of things that give trouble in engines of conventional design and that are present here. First is the stuffing box. Next are the cylinder heads, in the ordinary sense of the word, which are replaced by stationary pistons free from casting complications and transmitting the working loads of the engine to the framing in a very direct manner. During the high-pressure part of the cycle the rings on these heads seal off the ports inlet in the moving cylinder exactly as is done in the Knight engine. (*Motorship*, vol. 9, no. 4, April, 1924, pp. 261–263, 5 figs., *d*)

MACHINE PARTS AND DESIGN

A New Enveloping Worm Gear

A NEW enveloping worm gear developed by F. J. Bostock and now manufactured in England is based on the principle of straight-line generation.

Let *OJ* be the surface of the worm thread moving in the direction of the arrow, as shown in Fig. 2, and let *P*, *W*, and *R* represent the forces acting on it. If the worm thread *OJ* be moved at a uniform rate longitudinally, parallel to its axis, in the direction of the arrow, as shown, then it will drive the wormwheel in exactly the same manner as if it were caused to rotate at a uniform rate, because all linear sections are identical. If, therefore, the worm rotates uniformly in the direction *O*, then the point *O* will move uniformly in the direction *W;* hence the point of contact between the worm and the wheel must move uniformly along the resultant *R*.

Now the line *OR* touches the worm cylinder at only one point, *O*. Any other point of contact between the worm and the wheel along the resultant *R* will therefore be on a portion of the worm thread projecting above the worm cylinder. But *R* is in the horizontal plane contained by *W* and *P*, and as any point of contact along *R* is an intersection of the worm thread *OJ* and the resultant *OR*, it follows that the worm thread must be of such contour that it lies along a straight line *OJ* at right angles to *R*, and therefore inclined at an angle β to the plane *AB*. Clearly the angle β is equal to the lead angle of the worm.

Fig. 3 shows the positions of the straight lines *EF* and *EG* (corresponding to *OJ*) on the threads of a left-handed worm. Worms produced according to this principle were capable of rectification after

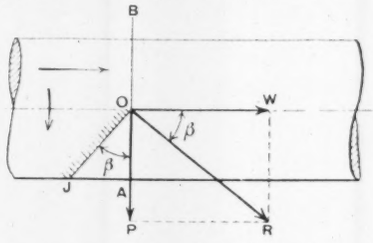

FIG. 2 ILLUSTRATION OF THE STRAIGHT-LINE PRINCIPLE AS APPLIED TO WORM GEARS
(The straight line *OJ* lies on the thread contour of the worm.)

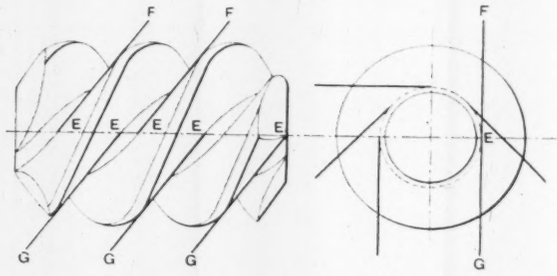

FIG. 3 PLAN OF THE NEW WORM, INDICATING SYSTEM OF STRAIGHT-LINE GENERATION

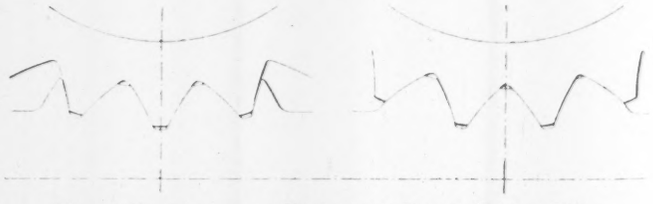

FIG. 4 ENGAGEMENT IN ENVELOPING TYPE OF WORM GEAR

hardening by means of a grinding wheel cutting on a straight-line system.

As shown in Fig. 4, the threads of the enveloping worm—which is a Hindley hour-glass or globoidal type of worm—and the teeth of the wheel actually embrace each other and automatically provide a tapered oil film between them. At the same time, owing to the fact that the threads of the worm, as the latter is revolved, travel round the radius of the wheel, there is no undercutting, the worm thread almost completely filling the space of the wheel throughout the whole of its travel.

The worm is automatically generated and lends itself to accurate grinding by means of a straight-sided abrasive wheel. The method of its generation is explained in the original article. The load-carrying capacity and life of the wheel are said to have been demonstrated in actual service on a number of London omnibuses on which the gears have been run upward of 40,000 miles with complete satisfaction. (*Machinery*, London, vol. 23, no. 499, Mar. 20, 1924, pp. 819–820, 4 figs., *d*)

MOTOR-CAR ENGINEERING

A New Variable Transmission

THIS transmission was developed by a concern in England in an unsuccessful attempt to produce a mechanism which would give it direct drive on all speeds.

For this purpose the propeller shaft was keyed to a disk having on it three circles of hardened pegs, the circles being of different diameters and corresponding to the three driving gears. Meshing with these pegs was a spur wheel bolted to the differential casing of the axle, but able to slide, so that its teeth could engage successively with the three circles of pegs. This type of gear is somewhat reminiscent of the gears provided on the early Quadrant bicycle.

It proved, however, difficult to make the mechanism compact and at the same time afford the necessary variation of gear ratios required by a modern car. Accordingly, an alternate form of transmission has been evolved in which the propeller shaft drives the disk through reduction gearing; in other words, the direct drive is abandoned in this particular case. By bringing in reduction gearing the size of the disk can be reduced very greatly and the mechanism made much more compact, while another spur wheel is introduced in order to provide a reverse. The construction of this combined

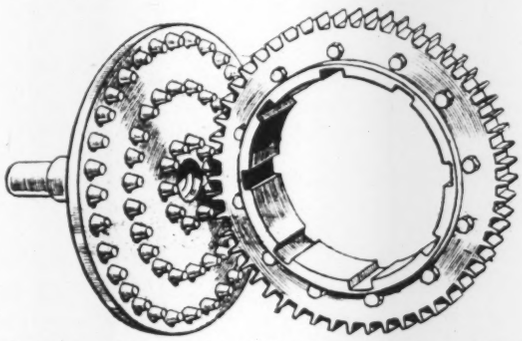

FIG. 5 THE DISK WITH ITS THREE CIRCLES OF PEGS, OF WHICH ONE IS ENGAGING WITH THE DRIVEN SPUR WHEEL

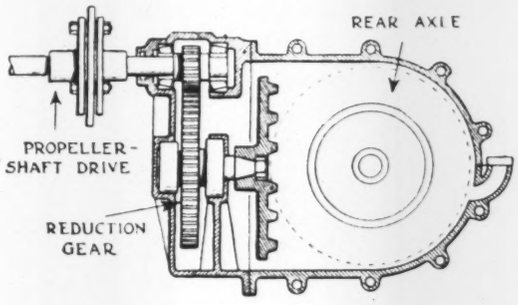

FIG. 6 REDUCTION GEARING INTERPOSED BETWEEN THE PROPELLER SHAFT AND THE DRIVING DISK SHOWN IN FIG. 5

gear box and final drive is plainly shown in Figs. 5 and 6. None of the tests referred to, however, has been carried out with the complete mechanism as it is illustrated here.

The better course was considered to be first of all to try out the durability of the pegs when driving a spur gear with the usual spur-gear teeth. For this purpose a car was fitted with a special rear-axle casing embodying the driving member of the gear but with one circle of pegs only, and the driven spur wheel and this set, not too well supplied with lubricant, has been used for some time with good results. It is not so noisy as gears of this type often are, and it appears to be standing up to its work satisfactorily. In the test set one gear ratio only is in use, and the teeth and pegs are subjected to very great stress, because on this one relatively high gear the car has to be restarted after every stoppage during the course of the tests.

It will be noticed that one of the chief claims of the gear to consideration lies in the fact that there is really a less number of parts than there would be in the ordinary gear box, for the effect of no less than three gear wheels is obtained by the rings of pegs on one disk. The shafts could hardly be shorter. (*The Autocar*, vol. 52, no. 1485, Apr. 5, 1924, p. 602, 3 figs., *d*)

POWER GENERATION

Steam Power from Internal Heat of the Earth

AT DEVIL'S GULCH, Sonoma County, California, there are two drilled wells which deliver steam that is being used in steam engines to generate electric current for light and power. A third well, half a mile distant, is now being drilled, and it is expected to supply the town of Healdburgh, lying 23 miles away, with sufficient current for lighting and heating. It is confidently estimated that the well will have a capacity of 2500 hp.

The subterranean reservoir from which the steam issues is supposed to be ten miles long and half a mile wide. It will be remembered that if the volume of steam be sufficient the pressure need be but little above that of the atmosphere, as a condenser may serve to produce the necessary vacuum to induce an effective pressure of ten pounds or more. (*Compressed Air Magazine*, vol. 29, no. 4, Apr., 1924, p. 844, *d*)

Pandora's Box

THE article here abstracted deals with the so-called Giant Power or Superpower idea in its broadest sense and discusses reactions which the concentration of power generation in a few huge units are expected to have on the economic and social phases of modern life.

The author claims that we are on the threshold of a technical revolution, and whether this revolution heralded by Giant Power shall proceed without the evil concomitants of its predecessor (the mechanical inventions of the 18th and 19th centuries) depends very largely upon the resoluteness of the social professions in winning acceptance for their standards of health, education, and spiritual freedom as basic, and their capacity to achieve a working alliance with the mechanical engineers, such as proved so effective recently in the matter of the long day in steel.

It would seem to be the opinion of the author that those whom he calls "human engineers" have not developed to the point where they are capable of wrestling with the momentous problems presented to them. They have been content to be camp followers rather than patriots in their own right, Red Cross workers to the captains of industry rather than co-equals in community building.

Through the development of the electrical industry the mechanical engineers are reconstructing the material foundations of America; the human engineers are hardly aware that a new technical revolution is on.

The control of Giant Power, which is essentially monopolistic in character, involves questions of public policy in reference to business enterprises that are charged with highly explosive prejudices. Standing as he does on neutral ground with respect to these political issues, the human engineer is in a peculiarly advantageous position to demand all the facts and to appraise them dispassionately in the light of established standards of civilized life. But facts without concrete plans and the capacity to use them are dust in the wind. Social engineers face the new technical revolution almost as naively as the philanthropists of the 18th century faced the old.

A nation's capacity for commodity production rises in approximately direct ratio to the amount of mechanical energy placed at the disposal of its individual workmen. The rapid increase of coal production during the last century gave American industry foremost rank in production per man. The same rule holds for wages. Mechanical horsepower per workman in England is about half that in the United States and British wages are about half of American wages; in Japan both horsepower per man and wages are about one-fourth of those in the United States. A disproportionate increase in the cost of mechanical energy would rapidly impair America's differential advantage and put the economic brakes on the advancing standard of living.

The author then proceeds to discuss industrial wastes and cites wastefulness of the present system of railroad operation by coal as compared with complete railroad electrification under the giant power system and the waste of coal in smoke as compared with burning it under by-product recovery methods.

The general bearing of such colossal wastes on wage disputes in the coal fields, on industrial unrest everywhere, and on our national standard of living is obvious. Their immediate bearing

upon giant power is that it is only through the full development of the coal by-product industry as an ally of electrification that electricity from coal can be supplied as cheaply as hydroelectricity at favorable locations like Niagara Falls.

The immediate objective of Giant Power is the conversion of all our primary energy resources into electricity and their pooling into regional systems which will then be integrated into a nation-wide federation of systems. There is abundant evidence that our commercially available energy resources—the mechanical energy at the disposal of the individual workman—are in process of incalculable increase.

But nowhere in America today outside of Ontario and parts of California can one find evidence that the people are socially aware of the inchoate changes, and nowhere are the social workers walking in step with the mechanical engineers to whom the author ascribes the gift of far vision.

He says that mechanical engineers have developed a technique for the conversion of their dreams into realities and are no longer afraid of mistakes and abortive experiments, because it is only through the process of trial and error that success can be achieved.

Mechanical energy is the life blood of our modern civilization. The issue upon which any effective alliance between the human and the technical engineer must inevitably center is whether in the development of giant electrical power primary consideration shall be given to the service of the home, the farm, and small community, where neighborliness and fertile groupmindedness are possible, or the further intensified development of mass production in already crowded and slum-breeding areas.

In the past the steam engine led to the concentration of machinery and workers within small areas. Giant power can be made to give to the forms and small communities equal access with the metropolis to cheap mechanical energy in its most convenient form, and by this it promises to decentralize population, and while conserving the advantages of machine production, to restore to the individual craftsman the opportunity for creative workmanship on an economic basis. It is highly significant that the Pennsylvania Giant Power Survey Board had made the service of the farm its first consideration and that decentralization and the increasing attractiveness of the small town and farm have been conspicuous results of large scale development in the Province of Ontario.

Giant power is in the estimation of the author a Pandora's Box, because it stands ready to loose upon the world a number of plagues, and the author asks whether knowing in advance what is in Pandora's Box shall one let the lid be lifted, or by taking counsel together seek to win the nascent blessings of the new technical revolution without turning loose its potential plagues. (Robt. W. Bruère, Associate Editor and Director of the Bureau of Industrial Research, in *Survey Graphic*, vol. 4, no. 6, March, 1924, pp. 557–560 and 646–647, illustrated, *g*)

RAILROAD ENGINEERING

British Geared-Turbine Condensing Locomotive

DESCRIPTION of the Reid-Macleod type of locomotive recently completed by the North British Locomotive Co., employing geared turbines directly applied.

The turbines are placed longitudinally, actuating the driving wheels directly, and as coupling rods are not used, while otherwise motion is entirely rotary, practically perfect balancing is secured. The absence of reciprocating members of any kind in itself constitutes an important advantage, in that the balancing problems associated with ordinary locomotive practice are entirely avoided. This consideration is further of importance, since the track and bridges carrying it are not subject to the running shocks associated with usual practice. This feature may also open the way for rendering heavier weights on driving wheels to be permissible.

From the traction point of view, great advantage follows from the fact that the turbine gives uniform torque, and as a result rapid acceleration is obtainable, equal to that which can be secured by means of electric traction. In order to enable the turbines to show their full thermal efficiency, a condenser is provided. This provides a vacuum for the exhaust from the turbine and a continuous supply of hot feedwater free from all impurities to be returned from the hot well to the boiler. The combination of two-stage turbines with a condenser secures expansion of superheated steam from boiler pressure to condenser vacuum, and an estimated economy of approximately 50 per cent in fuel and water should be obtained with this steam turbine condensing locomotive. The forced-draft apparatus insures steady combustion in the firebox; the rate of combustion is also under complete control and can be adjusted to meet all conditions of varying load and speed. A closed system of lubrication is installed, thus effecting a substantial economy in labor and in oil, insuring all the parts of the motion with adequate lubrication, and reducing the wear and tear to a minimum.

The original article shows two external photographs of the locomotive and states that it will be shown at the British Empire Exhibition at Wembley, April, 1924. (*Railway Gazette*, vol. 40, no. 15, Apr. 11, 1924, pp. 536–537, 2 figs., *dA*)

Developments of the Ljungstrom Locomotive

DESCRIPTIVE data on this locomotive were published in MECHANICAL ENGINEERING, vol. 44, no. 8, Aug., 1922, p. 535.

In 1923 the locomotive was removed from service and some of the parts redesigned. The most important of these was the replacement of the stationary-type air preheater with a new Ljungström rotating type (see MECHANICAL ENGINEERING, vol. 44, no. 10, Oct., 1922, p. 664). With these changes but without any material alterations, the locomotive was again placed in service in October, 1923. Since then it has been operating in various classes of service with the purpose of demonstrating its durability and adaptability. It was first employed in switching service principally to ascertain the reliability of the reversing mechanism and the ease with which it may be controlled, as well as to demonstrate its starting force. It was then placed in service on slow freight runs between two towns, a distance of about 25 miles, with 9 stops, for setting out and picking up cars and doing station switching. The usual weight of the train, exclusive of the locomotive, was 350 to 375 tons. On one occasion, however, the train weighed 718 tons over the last part of the trip which included several long 1 per cent grades. The performance of the locomotive in starting and accelerating the heaviest of these trains is said to have been entirely satisfactory and a large part of the time was consumed in switching at stations.

An inspection was then made and the only defect found was one boiler tube leaking. The third period of service began on November 30, 1923, and is still continuing. The locomotive is at present running in express-train service on the main line between Stockholm and Gothenberg, alternately on passenger trains making frequent stops and on fast express trains. About half of the distance between these two places constitutes the run of the turbine locomotive, which is averaging about 250 miles per day. The average weight of the train, exclusive of the locomotive, is about 300 tons, and the coal consumption of the turbine locomotive averages about one-half of that required by locomotives of the reciprocating type. The locomotive is said to have developed marked accelerating capacity, with freedom from jerks and shocks in starting the train.

Early in 1923 an order was placed by the Swedish State Railroads with Nydquist & Holm, Trolhätten, Sweden, for the construction of a second turbine locomotive, generally similar in construction to the original locomotive as it has now been modified. This locomotive will have a total weight of approximately 322,000 lb., including both the boiler car and the condenser car, under which the driving axles and turbine are located. It will develop 2000 effective hp. at the rail and will be designed for a maximum speed of 60 m.p.h., to meet the limitations of speed imposed by the Swedish State Railways. An order has also been placed by the Argentine Republic Government with the same builders for a locomotive of this type to develop 1750 b.hp., which will burn oil fuel. This locomotive is being built under a guarantee calling for a fuel and water capacity sufficient for a 500-mile run lasting 20 hr., without replenishing. About 23,500 lb. of water will be carried, approximately half in the condenser and the remainder for feedwater. The fuel requirement is 14,500 lb. of oil having a heating value of 18,900 B.t.u. per lb. Late in 1923, Beyer, Peacock & Co., Manchester, England, obtained a license to build Ljungström turbine locomotives in the British Empire. This company now has under construction two locomotives, one to equal or exceed in size or speed the largest locomotive

on English railways, and the other for service in India. Locomotives of this type for both passenger and freight service have been designed to develop 4000 hp. and arrangements are being made for their construction in the United States, under the patents of A-B. Ljungströms Angturbin, New York. (*Railway Age*, vol. 76, no. 17, Mar. 29, 1924, pp. 849–850, 2 figs., *g*)

Performance Tests of the Locomotive Booster

THE tests described in this paper cover a wide range. A chart in the original paper illustrates the accelerating possibilities of the booster and also shows its effect in pulling a heavy train up grade at a speed higher than the locomotive could attain alone. In this latter respect it was found that on a grade of 0.5 per cent a steady train speed without the booster is 6 m.p.h., while with the booster in operation it is 16 m.p.h.

The booster acceleration is particularly evident on grades. For example, with a grade of 0.3 per cent the increase in acceleration due to the booster is 87 per cent; which means that without the booster, assuming the weight of the locomotive and tender to be 400,000 lb., the acceleration would be 0.69 ft. per sec. per sec. or 0.047 m.p.h. per sec., while with the booster in operation the acceleration would be 0.128 ft. per sec. per sec. or 0.087 m.p.h. per sec.

Before shipment each booster receives a thorough test on a dynamometer and Fig. 7 shows the brake horsepower and indicated horsepower at different speeds with the mechanical efficiency plotted out over a range of speeds. This high overall mechanical efficiency, which is between 90 and 95 per cent, is particularly noteworthy when it is considered that the power or torque is transmitted from the booster to the trailer axle gear through gearing.

The paper next discusses the relation between the locomotive booster and limited full-gear cut-off. The author comes to the conclusion that because of the presence of the booster, locomotive designers may now deliberately over-cylinder the locomotive, thereby obtaining at the higher speeds a substantial increase in

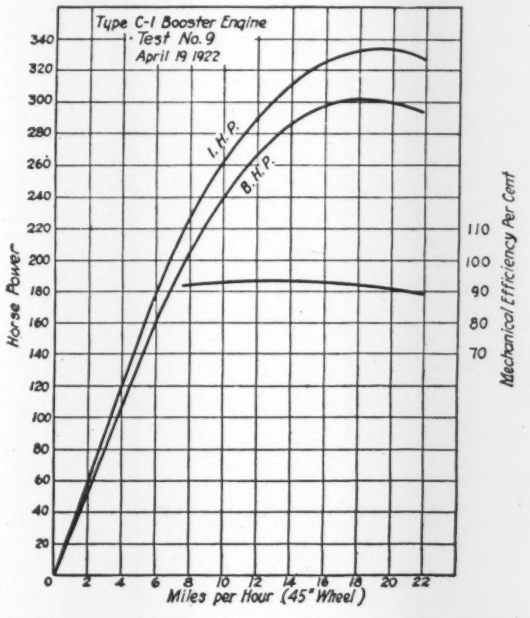

FIG. 7 BRAKE HORSEPOWER, INDICATED HORSEPOWER AND MECHANICAL EFFICIENCY AT DIFFERENT SPEEDS—BOOSTER-EQUIPPED LOCOMOTIVE

drawbar pull by operating at the shorter cut-off with increased steam economy. It also prevents slipping at start.

Fig. 8 shows graphically what happens. The tractive effort curve, marked "A," is a typical curve of the conventional type of Mikado locomotive having a starting power of 60,000 lb. The factor of adhesion at start is just about enough to eliminate slipping. This curve shows the natural characteristics which obtain with increased speed up to 35 m.p.h. Interrelating the booster with limited full-gear cut-off into a Mikado engine of the new design, consuming approximately the same steam consumption, results in the tractive curve "B."

At 20 m.p.h., the power of this new engine is 5.6 per cent over that of the previous engine, and if this engine were operated on full-gear cut-off at start, it would deliver close to 70,000 lb. tractive effort, and having the same weight on drivers, would ordinarily upset the locomotive equation as it would be a very slippery engine and would cause a great deal of trouble.

It will be noted in this connection that the starting power with the booster is higher than could possibly be attained if the full-gear cut-off was carried and if the engine did not slip. (M. H. Roberts, Mem. A.S.M.E., Vice-Pres., Franklin Railway Supply Co., New York, N. Y., in an address before the Boston Section of the

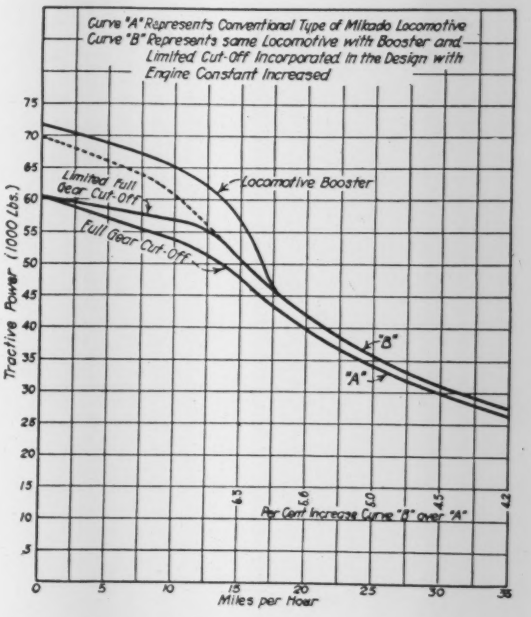
Curve "A" Represents Conventional Type of Mikado Locomotive
Curve "B" Represents same Locomotive with Booster and Limited Cut-Off Incorporated in the Design with Engine Constant Increased
Limited Full Gear Cut-Off
Locomotive Booster
Full Gear Cut-Off
"B"
"A"
Per Cent Increase Curve "B" over "A"
Tractive Power (1000 Lbs.)
Miles per Hour

FIG. 8 TRACTIVE-EFFORT CURVES FOR LOCOMOTIVES WITH AND WITHOUT-BOOSTERS AT VARIOUS SPEEDS

A.S.M.E., Feb. 7, 1924. Abstracted through *Railway Review*, vol. 74, no. 17, Apr. 26, 1924, pp. 765–769, 8 figs., *e*)

SPECIAL MACHINERY

Centrifugal Driers and Separators

THE basket is the feature of centrifugal apparatus having the most important influence on the design. The wire basket used to be popular in the early days of centrifugals, but the perforated steel cage is more widely used now. Copper baskets are also used, and baskets generally are often coated with vulcanite and sometimes with lead.

One of the most important features of the basket is the method of discharge. The basket may be fitted with one or two doors in the bottom which may be opened at the conclusion of the operation and the dried material pushed through an opening in the casing on to a chute which takes it clear of the machine. Another method is to have a lifting-out basket fitted with trunnions. Center-discharge baskets are standard in the sugar-refining industry, and there are also baskets of the self-discharge type.

As regards speeds, they vary usually between 8000 and 12,000 ft. per min., although some smaller machines 12 in. in diameter and under when used as separators go as high as 16,000 or even 18,000 ft. per min.

Centrifugals may be classified into three types, namely, fixed-spindle machines, suspended machines, and free-spindle or self-balancing machines. The third class may be subdivided into the peg-top or under-driven and Weston or top-driven varieties.

The author proceeds next to discuss the behavior of material when treated in a centrifugal drier, in particular the influence of wide variations in speed on the efficiency of the machine. He comes to the conclusion that this influence is very small. (By efficiency is here meant the proportion which the remaining liquor per 100 lb. of solids bore to the original quantity as it entered into the machine.)

The question of distribution of the moisture in the various por-

tions of the load is of interest. The wettest part is generally next to the basket wall, and the driest on the inner wall of the load. Some interesting tests were made by the writer on salt, spun in a 48-in. machine, with a view to determining what was an average sample. The results are indicated in a diagram in the original paper, where it will be observed that the moistures, after a run of 7 min. at full speed, were remarkably even and regular, but increased slightly from inside outward and from top to bottom. The average size of the crystals at each point approximated closely to 0.2 mm., the largest being 0.5 mm.

As regards labor and output, the following data are presented on one concrete case. In a plant handling sulphate of ammonia there were a number of units, each having a single centrifugal to take the salt as it came from the saturator. The baskets were 42 in. in diameter, but only 17 in. deep, and the average load was about 3 cwt., with a maximum of about 4 cwt. of whizzed salt. One man attended to the saturator and centrifugal, the dried product from which fell on to the boot of an elevator, whence it passed to conveyors and rotatory driers. Here a timed operation was as follows:

Filling	3 min.
Drying	3 min.
Stop, empty, restart	4 min.
Total	10 min.

Here the average for any machine kept up fairly well to the unit operation so long as sufficient salt was available, but was apt to drop a little through various causes when the whole battery was considered over a shift.

Separators or subsiders are centrifugals which have no holes in their baskets. They can be used to remove from liquids solid particles so fine that they would choke any filter cloth or for separating two liquids one from another, such as water from tar. The liquid is fed to the bottom of the basket through a baffle or distributing ring which brings the water up to the basket speed as it enters. Instead of gravity centrifugal force makes the liquid form a substantial vertical wall level with the lip of the basket. If the mixture of two liquids is fed into a tank with a baffle plate in the middle the heavy liquid will sink and pass under the baffle, where it rises again owing to being pushed up by the head of liquid on the other side. If the tank is correctly proportioned none of the light liquid will pass below the baffle but will stay above the heavier one, so that spouts can be arranged one on each side which will deliver pure heavy and pure light liquid, respectively.

Among the applications of centrifugal separators is the treatment of heavy fuel oil for Diesel engines. While a "gas" of "Diesel" oil has been used in the past, there has been a tendency lately to use a heavier oil known as "boiler" oil, having a specific gravity of 0.95 to 0.96. It was found to score the cylinder liners due to the high ash content, which was about 0.065. This could be brought down in a high-speed centrifugal to about 0.022—an amount similar to that of an ordinary Diesel oil. Such machines work quite well aboard ship and pass some 250–350 gal. per hr., the bowl being changed over at the end of each watch. A separate overflow for any water is provided, so that in addition to freeing from ash there is given security against water being injected into the engines.

Another interesting development is the handling of a water-gas tar in which oil forms a very intractable emulsion in water. A very inefficient separation is accomplished by gravity and heat and requires some nine to twelve months to complete. The finely divided carbon present acts as an emulsifying agent, and its density causes it to be removed almost immediately the emulsion enters the centrifugal. The latter is now free to separate with far greater ease at a rate of some 170 to 180 gal. per hr. (Paper before the Hull Chemical and Engineering Society, March 4, 1924, by E. A. Alliott. Abstracted through *Chemical Age*, vol. 10, no. 247, Mar. 8, 1924, pp. 236–238, 1 fig., *d*)

The Modern Rotary Drilling System

THE rotary system was invented or rather developed during exploitation work in the Gulf Coast regions of Texas and Louisiana where soft and caving formations were encountered and gave the cable tools a bad time. By this method a rigid stem of pipe rotates a fishtail or other type of bit at the bottom of the hole, being assisted by the action of clay mud in the fluid state pumped under hydraulic pressure through the drill pipe. The circulating mud also removes the cutting from the hole.

The extreme speed attained with this type of equipment, and the few strings of casing necessary, are its chief assets. It is not unusual in a rotary field for a good crew to average 450 ft. of hole per day. Wells have been drilled to a depth of 5000 ft. with only two strings of casing. The rotating action of the bit and drill-stem causes the mud to be thrown against the walls of the hole, plastering them thoroughly and penetrating porous formations to a very small extent, where it "muds-off" water and gas. This mudding of the walls saves casing, and prevents water and gas troubles, as the static pressure of the mud in the hole tends to balance excessive gas and water pressures.

This paper deals particularly with the application of rotary drilling in California where the heaviest equipment is used, the machine weighing over 8000 lb. (the weight of the rotary machine used in Gulf Coast fields where comparatively shallow depths are drilled is only about 4600 lb.). The heavy machine is of course more costly, but it is ultimately more economical than the lighter type.

Power is supplied by steam, gas, or electricity. When steam is the method employed it is usually supplied by one large, portable, locomotive-type, fire-tube boiler. In very deep fields two or three boilers totaling about 140 hp. are commonly used. The engine may be either a single-cylinder, double-acting, steam engine of 12 in. bore and stroke, or a 10-in. by 10-in. twin-cylinder double-acting steam engine. The twin-cylinder engine has several decided advantages over the single in rotary drilling, the chief of which is the alternating action of the pistons.

In rotary drilling it is continually necessary to reverse the engine rapidly when the bit encounters a break in the formation, or a boulder which it cannot penetrate nor dislodge. Unless the twisting force on the drill pipe is quickly relieved, the pipe will be broken in two. It takes some appreciable time for the impetus of the heavy flywheel on a single-cylinder engine to be overcome and the engine reversed, but the reverse can be accomplished immediately with the twin engine. The flow of power from the twin engine is also much more regular and sustained, and there is ample power for rapidly raising a heavy string of drill pipe from great depths. Both the single- and twin-cylinder engines, whichever form is used, are provided with a chain sprocket for driving the lineshaft on the draw works.

In many fields where electric current is available, rotary rigs as well as cable-tool outfits are being operated by electric motors. The standard equipment for running a rotary rig by electricity is a 75-hp. induction-type motor, of 50 or 60 cycles. The equipment for this motor consists of a main and auxiliary controller with main and auxiliary resisters, oil circuit breaker and current transformer. The motor operates on alternating current, and the control equipment provides for a very wide speed variation, a range of 153 speeds being possible. The drive from the motor to the lineshaft is through a reduction gear, and from the gear to the lineshaft by sprocket chain.

The slush pumps are also operated by electric motor, the motor in this case being a 50-hp. 60- or 50-cycle induction-type motor, and the control equipment practically the same as for the drilling motor. The slush pumps are of a slightly different design when electricity is the motive power, the steam end being replaced by gears with a heavy belt pulley mounted on the crankshaft. Two slush pumps are always used in a rotary rig, so that in the event of repairs being necessary on one, there is always another in reserve.

The power-driven pumps are provided in pairs with the pulleys mounted right and left hand, the motor being mounted on an adjustable base which permits lateral movement of the motor to transfer the driving belt from one pump to the other.

For gas and oil engines which are also used in rotary drilling the usual installation is a heavy-oil-country-type 75-hp. engine, which will run on either natural gas or a low-grade distillate. Although internal-combustion engines are widely used for pumping wells, and are in fairly common use for cable-tool drilling, their application to a rotary rig is of quite recent introduction and of limited extent, so that it is not possible at present to give an opinion as to the relative merits of oil and gas engines in comparison with

steam or electrically driven rigs. When an internal-combustion engine is used the drive is stepped up from the engine to the line shaft via a countershaft. Whatever form of power is employed, all the controls are on the right-hand side of the draw works, which is the position in which the driller stands while operations are proceeding, and from which point he has full control of the draw works and the power unit.

The draw works serves as a hoisting gear for handling the drill pipe and as a transmission between the engine and the rotary machine. It is a very heavy structure. As the tendency for the rotary machine is to be run at continually increasing speeds, a three-speed rotary draw works was recently introduced to meet this condition.

The rotary machine is a device for gripping and turning the drill pipe. It consists of a heavy horizontal steel turntable carried by a heavy annular cone roller bearing on a massive base. The table is held down on the bearings by large hold-down brackets bolted to the base and engaging a flange on the vertical skirt of the table. The drill string, the upper or working joint of which is square passes through a square hole in the table, and is driven by suitable bushings engaging both table and drill stem. The table has gear teeth on its under side, which are engaged by the pinion on the pinion shaft carried in bearings on the base. The pinion shaft is driven, either by a sprocket chain from the lineshaft of the draw works, or by a direct shaft drive.

The mud-laden fluid is circulated by two powerful direct-acting duplex steam pumps working alternately. The abrasive action of the mud causes the packing and plungers and valves to be comparatively short lived and these are designed for easy replacement. For light drilling these pumps have $5^3/_4$-in. water cylinders, 10-in. steam cylinders, and a 12-in. stroke. The heavy-duty pumps are $6^3/_4$ in. by 12 in. by 12 in. or $6^3/_4$ in. by 12 in. by 14 in. Each pump has a separate suction pipe to the mud pit. The discharges are connected by a manifold to a standpipe running for about 20 ft. up to the side of the derrick. A flexible hose connects the top of this pipe with the swivel on the drill stem.

The rest of this very interesting article is not suitable for abstracting. It shows, however, the engineering features of this method of drilling. (L. R. McCollum in *Journal of the Institution of Petroleum Technologists*, vol. 10, no. 41, Feb., 1924, pp. 1 to 26 and discussion pp. 26–41, 9 figs., *d*)

TESTING AND MEASUREMENTS

How to Compensate for Temperature Effects on Hydrostatic Gages

THIS article described the hydrostatic gage in its simplest form and points out that such a gage, because of the temperature effect on the air in the pipe, is absolutely useless unless this effect is eliminated or compensated. The way to make such a gage independent of temperature variations is to keep the liquid out of the pipe immersed in the tank at all times and calibrate the gage to register the net height of the liquid in the tank. This can be done by adding an air valve to the pipe communicating between the tube inserted in the tank and the gage proper and pumping air into this pipe through this valve every time a reading is taken.

Another way of temperature compensation is by maintaining a liquid column of a constant height in the pipe immersed in the tank, this being done by means of suction from the vacuum tank through the valve on the communicating pipe referred to. Here the gage registers the height of the column which represents a difference in the heights of the liquid in the pipe and in the tank.

One disadvantage of this arrangement is that the liquid in the gage may become ejected through the open end of the U-tube if the engine suction is applied to the valve when the tank is empty. Also that air is drawn from the bottom of the pipe immersed in the tank, or if the liquid is shaken out of this pipe or evaporated when the car is shipped with an empty tank.

Instead of the U-tube a diaphragm gage or indicator is sometimes used, although a diaphragm possesses certain disadvantages; it has a certain amount of internal friction which reduces the accuracy of the instrument; the accuracy is further reduced by the friction and lost motion on the transmitting gears and links. Besides, unless the diaphragm is properly aged, its elasticity changes with use. This arrangement cannot be used on tanks under air or gas pressure.

The author describes also an arrangement in which the temperature compensation is accomplished automatically without any mechanical devices, and then proceeds to the mathematical discussion of the dimensions of the pipes and tubes of the gage. (J. P. Nikonow. *Automotive Industries*, vol. 50, no. 18, May 1, 1924, pp. 964–966, 3 figs., *gp*)

CLASSIFICATION OF ARTICLES

Articles appearing in the Survey are classified as *c* comparative; *d* descriptive; *e* experimental; *g* general; *h* historical; *m* mathematical; *p* practical; *s* statistical; *t* theoretical. Articles of especial merit are rated *A* by the reviewer. Opinions expressed are those of the reviewer, not of the Society.

Relation of Mechanical Engineering to Management in the Textile Industry

(*Continued from page 344*)

engineer had grown up in the mill together. The former, an excellent mill man, but with no particular engineering knowledge, regarded exhaust steam as a waste product. In fact, he called it waste steam. He was genuinely pleased at his engineer's adaptation of this waste product to a useful purpose, and put himself strongly behind the idea. Even after the engineer's visit and report he seemed to consider that with or without a condenser exhaust steam was waste, and that back pressures were an engineering hallucination. Because of his excellent record in the mill, he had the confidence of his superiors and his adverse comment on the engineer's report resulted in its rejection. It is interesting to surmise just what would have been the result had the engineer taken time to explain in simple, non-technical language to both the plant engineer and the agent, the functions of a condenser and the difference in efficiency between a non-condensing and a condensing engine. The mill is still heated by exhaust steam.

On the other hand, during the boom of 1919–20 a large mill had the misfortune to have four of its boilers condemned. This, too, was an open-and-shut case. The boilers had been required in the past—they would be needed in the future; the management did not require an engineer to make that fact clear. Because of representations made to the treasurer as to the possible value of engineering opinion, at this point he announced himself open to conviction in that he would gamble one day's pay (the engineer's, not his own) on any possible benefit the plant might receive from engineering. The engineer in question, being a rapid worker, spent the one day in the mill and in his report to the treasurer developed the fact that the stack was too small both in diameter and in height, and granting a proper stack at a cost of about $20,000 he could do away not only with the four condemned boilers but with one in addition. Replacement of the boilers could be made at a cost of $100,000, so therefore the engineer's saving in the plant account alone amounted to $80,000. This saving included in addition one foreman and seven tons of coal a day. It is of interest that the engineer, imbued apparently by the speed indicated in his one day's contract, spent $90 in employing a traffic man to expedite the stack material. This item was disallowed by the treasurer on the grounds that it was not a necessary engineering service!

There is no doubt but that management is "hard-boiled." Apparently the process of separating the wheat from the chaff, in so far as new ideas are concerned, tends toward a bleakly conservative attitude, perhaps, to round out the simile, because of the small percentage of wheat found. It is equally true, however, that once convinced, management is quick to utilize an idea, to provide the proper channels for its efficient functioning, and incidentally to fix the responsibility for its performance.

Practically all of the engineering facts in this paper are due to the kindness of various members of the Lockwood, Greene & Co. engineering staff, who drew freely on their experience for the author's benefit.

The Hardness of Metals and Hardness Testing[1]

Some Observations on the Nature of Hardness, together with Descriptions of Various Methods Used in Testing

IN AN ADDRESS before the American Society for Steel Treating not long ago, Dr. H. P. Hollnagel said that the term "hardness" is used to denote many different things. An editorial writer in London *Engineering* (Apr. 27, 1923) says that—

> Until our physicists have come to some agreement as to what property of the molecules of a substance, or what configuration of these molecules gives the quality to a material which we connote by hardness, the subject will never be put on a really scientific basis. There are enough and to spare of so-called "hardness tests," and nothing is to be gained by devising any more. If a certain Brinell number, scleroscope number, or scratch width is found to be associated with the quality which is satisfactory for a certain purpose, then the particular number of width can be used as an acceptance test for the material. This, in fact, is what is done in practice, and further than this the engineer cannot go at present. In spite of all the efforts which have been made to justify the several tests by scientific considerations they still remain empirical determinations of an unknown quantity. If hardness is wanted in a material for the resistance of abrasion, the amount of abrasion produced under given conditions is the only true measure of the kind of hardness required. If penetration is to be resisted, as in the case of armor plate, some kind of penetration or indentation test is obviously suggested. If, on the other hand, hardness is taken as an indication of tensile strength, or of chemical composition, it is surely better, whenever possible, to determine these characteristics directly. The ease by which certain so-called tests of hardness can be applied to finished material without injuring it, and the pseudo-quantitative nature of the numerical results obtained, tend, by reason of their attractiveness, to disguise the fact that it is an unknown quantity which is being measured, and one which may, or may not, be correlated with the characteristics desired.

Coming back to the address of Dr. Hollnagel referred to above, we find that in his opinion the concept of hardness originates from a sense of resistance offered by material to the action of an approximately static force, and there seem to be two general classes of hardness—superficial hardness, otherwise referred to as resistance to abrasion—and penetration hardness, referred to as deformation hardness. Furthermore, a so-called academic definition of this engineering property intended to cover both classes is stated as follows: "Hardness is a cohesive resistance of the molecule-aggregate structure of a material to a deformation of form." Dr. Hollnagel adds, however, that for the engineer this definition is utterly worthless.

Of late, possibly under the influence of Sir Robert Hadfield in England, much attention has been devoted to the subject of hardness, and particularly hardness testing. The following methods of test have been either proposed or investigated more thoroughly than ever before.

The Scratch Test

This is by far the oldest test and historically goes back to the Moh mineralogical scale where all minerals were classified into ten groups by hardness, each group leaving a scratch mark on the one below it and being scratched by the one above. When, however, the scratch on the metal was obtained by a diamond point the question arose as to what was the exact relation between the width of the scratch and the hardness number.

This problem was recently thoroughly investigated by G. A. Hankins, of the National Physical Laboratory, Teddington, England. (Proceedings of the Institution of Mechanical Engineers, April, 1923, pp. 423–487.) The results obtained show that with the material used a straight-line law exists between the square of the width of the scratch and the load on the diamond. Furthermore, it is found that a law exists expressing a constant k for each material which may be taken as a measure of the hardness of the material in terms of load on the diamond and width of scratch. An effort to establish a ratio of the scratch hardness to the Brinell hardness would indicate that the scratch test measures a property of the material slightly different from that measured by the Brinell test.

The results of the investigation also show that the method can be utilized to obtain a measure of the "hardness" of metals (bearing in mind a special meaning of this term as applied to this particular test) on the same scale over a very wide range, but for general use in testing a standard shape of diamond would have to be adopted.

It would be well to call attention to the fact that Sir Robert Hadfield in his tests has established that except for the hardest specimens where the Brinell test breaks down the inverse cube of the width of the scratch produced on a specimen of steel under constant conditions of load and diamond is proportional to its Brinell test.

Brinell or Static Indentation Tests

In the Brinell test hardness is measured by the amount of penetration into the material of a standard ball to which is applied a standard force. Whether a penetration test can determine true hardness depends on a large number of considerations which cannot be discussed here for lack of space. It does not at all apply to the determination of very hard materials like manganese steel. Furthermore a material under compression changes in hardness and becomes more resistant to penetrations as the hardness increases up to the point of rupture of grain structure. Therefore, as Dr. Hollnagel points out, it would seem that hardness depends as much upon the degree to which material has previously been deformed as it does upon the rate at which this deformation has been carried out. If this is true, then data of penetration tests have no definite meaning of their own, but must be interpreted in the light of the history of the material tested.

In indentation hardness tests there is produced a highly complex type of deformation which varies in intensity from point to point in the test specimen. Such a test, it may be said, does not determine any simple fundamental property of the material, but this fact does not prevent it from being of great practical value for certain purposes.

From a practical point of view in determining the hardness of materials by the ball indentation test, it commonly happens that the piece of material available for the test is so small that the standard load of 3000 kg. cannot be applied. It is therefore of considerable importance to know the precise law of comparison which must be followed in these tests in order that the hardness number arrived at may be independent of the dimensions of the ball used. This subject is extensively discussed in a paper on Static Indentation Tests by R. G. C. Batson, National Physical Laboratory, Teddington, England, who bases his work on Mayer's law of comparison.

Mayer stated in 1908 that so long as the angle of the impression remained constant, the value of the total load divided by the projected area of the indentation was also constant, or, to put it in other words, the condition for constant pressure per unit area of indentation was geometrical similarity of the deformation produced.

Batson also goes into the subject of the comparison of the ball and cone methods of indentation testing. He comes to the conclusion that the hardness numbers obtained with the 10-mm. ball and calculated from the diameters of the impressions are not independent of the load, but that in the cone test the hardness numbers calculated from the diameters of the impression are approximately constant, and that those obtained from the depth of the indentation vary with the load. Batson was practically the first to call attention to the importance of the ridge about the indentation and to the fact that when the part of the impression caused by the ridge is neglected, the impressions under varying loads given by the ball test are similar and by the cone test are dissimilar.

A variation of the standard Brinell test, in which an etched ball is used instead of a smooth one, is described in the Report of the Committee of the Engineering Division of the National Research Council, published in Mechanical Engineering, vol. 41, no. 7, July, 1921, p. 445.

[1] Prepared at the request of the Special Research Committee on the Cutting and Forming of Metals.

THE HERBERT PENDULUM HARDNESS TESTER

This is a comparatively new development, essentially belonging to the same class as the Brinell test, with this difference, however that the Brinell microscope measures the indentation after the load has been removed, while the pendulum measures it while the load is on. Taking an extreme case, we may assume that if a Brinell test were made under suitable light load on wax and on rubber, the test would show the wax to be very soft and the rubber infinitely hard, as the diameter of the impression in the latter case would be zero. With the pendulum, tests on rubber are perfectly practicable. This illustration would indicate that indentation hardness is of two kinds, which may exist separately or be both present in proportions varying with different materials. These may be called "elastic indentation hardness" and "plastic indentation hardness," only the latter of which is measured by the Brinell test.

In the pendulum scale test the pendulum is placed on the specimen, making an indentation, and is tilted by hand till the bubble comes to zero. The effect of tilting is to elongate the impression made by the weight of the instrument. The pendulum is then released and in swinging under the influence of gravity causes the ball to roll back along the groove so formed. The scale hardness number is the position of the bubble on the scale at the end of the first swing.

It will be seen that this test is not purely a measure of indentation. The ball is, in effect, a tool working the material. If the material is easily worked, the ball pushes a comparatively large wave of material in front of it and soon exhausts the energy of the pendulum, giving a low reading. If the material is refractory, the ball tends to roll on its surface, doing less work and therefore giving a longer swing and a higher reading. The "scale" test therefore measures "workability," or, rather, its inverse, which it is proposed to call "work hardness."

The resistance which any material offers to working with a tool depends on two factors which all metals possess in different degrees and varying proportions, namely, resistance to penetration by the tool and resistance to flow. Thus a hard steel cannot be worked because it cannot be penetrated by the tool. It has high indentation hardness. Manganese steel has low indentation hardness and is easily penetrated, but cannot be worked because of its resistance to flow. It is proposed to adopt two new terms to distinguish these qualities: namely, "work hardness" or resistance to working, a composite quality consisting of (1) resistance to penetration by the tool (indentation hardness); and (2) resistance to flow, or "flow hardness."

It would appear that there are five distinct kinds of hardness, of which two are complex and three simple. (1) *Compound indentation hardness*, measured by the pendulum time test, a composite quality, comprising (1*a*) *plastic indentation hardness*, measured by the Brinell test, and (1*b*) *elastic indentation hardness*, measured by the pendulum time test on glass, rubber, and the hardest steels, but otherwise not yet isolated. (2) *Work hardness*, or resistance to working with a tool, measured by the pendulum scale test, a composite quality comprising *hardness indentation* as above and (2*a*) *flow hardness*, or resistance to flow, measured by the pendulum scale/time ratio.

Furthermore, Edward G. Herbert, the inventor of the pendulum hardness test, disagrees with Dr. Hollnagel's opinion referred to above in that he does not consider resistance to abrasion as a kind of hardness at all and believes that it is not an inherent property of any material but that it varies with the character of the abrading body.

THE ROCKWELL TEST

The Rockwell test is a modification of the Brinell. It consists of pressing a hardened steel ball or a diamond cone of 120 deg. angle, into the article to be tested and measuring the depth of impression with a dial micrometer. The size of impression is much smaller than in the Brinell test as the steel ball is only $^1/_{16}$ in. in diameter and the maximum major load is only 150 kg. when using the diamond cone and 100 kg. when using the steel ball. Arrangement is also made to apply a smaller load of 60 kg., if desired, for soft metals. The method of applying the Rockwell test is different from the Brinell in that the total depth of depression from the surface is not measured. In making the Rockwell test the minor load of 60 kg., regulated by a spring, is first applied to the ball or cone; the micrometer dial is then set at zero, or at a fixed point, and then the major load is applied. Upon releasing the major load the depth of impression caused by the major load only is indicated on the micrometer dial. By using a special reading glass, the diameter of depression of a steel ball can be read the same as in the Brinell test. The Rockwell test does not require a standard specimen, it does not spoil the finish of the article tested, except on very high-polished work, and it can be used on much thinner sections than the Brinell (0.010 in. for iron and 0.015 in. for brass); it cannot, however, be used for testing thin sections that are brittle or cannot stand a permanent deformation.

THE SHORE SCLEROSCOPE TEST

The Shore scleroscope test utilizes as a measure of hardness the height of rebound of a weight when allowed to fall from a given height upon the article to be tested. The scleroscope consists of a cylindrical weight $^1/_4$ in. in diameter by $^3/_4$ in. long having a diamond striking point, slightly spherical and blunt, about 0.020 in. in diameter. The weight is allowed to drop by gravity from a height of 10 in. through a vertical graduated glass tube on the article to be tested. The height of rebound is measured by noting the highest point of the weight against a graduated scale in back of the glass tube. Articles to be tested are placed upon a hardened steel anvil; the tube is clamped tight against the specimen and the weight released by an operated spring. For testing large specimens the tube can be removed and attached to a swing arm or held in the hand. The scleroscope does not require a standard piece for testing; it does not spoil the finish of the article to be tested; and it can be used on very thin sections and, by holding in the hand or swing, on very large sections.

STATIC-INDENTATION VS. REBOUND VALUES OF HARDNESS

The question to what extent static-indentation values of hardness such as are obtained by the Brinell and Rockwell tests compare with rebound values of hardness such as obtained by the Shore scleroscope is decidedly a mooted one.

The U. S. Bureau of Standards, for example, has frankly refused to undertake any kind of a compilation of a table that would give the conversion values between the Rockwell and Shore tests, taking the attitude that each test has a field of its own and that the values therein should be taken as such.

The subject has been rather closely investigated in a paper presented before the Iron and Steel Institute, no. 1, 1923, by Hugh O'Neill, University of Manchester. The conclusion to which the author comes is that it is perhaps unlikely to expect any true relation between scleroscope and Brinell hardness when one considers the very arbitrary nature of the two tests. Then again the physical dimensions of the two systems are different. That of the Brinell method is [Mass/Length^2] while the Shore hardness is a height of rebound having a dimension in [Length] only.

The above remark of Professor O'Neill calls attention very forcibly to one element in all hardness tests which is essentially absent from the majority of other physical tests, and that is its arbitrariness. When we measure time, yield point, breaking strength, weight, we are dealing with constants having a certain definite physical meaning. The breaking strength is the strength of the material above which certain clear phenomena occur, such as the parting of the molecules of the given material. It does not matter by what methods we measure this breaking strength, i.e., whether we apply weights at one end of a vertical steel rod having the other end rigidly held and subject the rod to rapid rotation so that the weight attached at its end will exert a centrifugal force, the stress at which the parting of the fiber will be produced will be exactly the same and with proper measuring facilities can be determined experimentally or analytically and should give the same results.

Furthermore when we measure, say, the breaking strength of a rod, it does not matter essentially what material the rod is made up of, and breaking strength means exactly the same thing for a steel rod, a glass rod, and a rubber rod.

When, however, we come to the measurement of hardness, we find an entirely different situation as we do not measure by any of

the means known today any specific property of the material. In the case of the scratch test we simply measure how the hardness of a given material like steel compares with the hardness of the diamond, without knowing what the hardness of the diamond is. By comparing how the hardness of two kinds of steel compares with the hardness of the diamond and by measuring the respective scratches, we obtain a certain basis of comparison—without, however, understanding the property which is really being measured. The Brinell and Rockwell tests cannot be applied to the measurement of such highly elastic materials as rubber, and it is by no means clear just what either of these tests measure, even in the case of steel.

The only apparent value of all hardness tests is the practical value.

There is one other element in all hardness tests which may and may not be of material importance and that is that all tests with the possible exception of the scratch hardness are applicable to materials of what might be called "uniform hardness," i.e., materials which do not contain spots of greater hardness than the matrix and are of very much smaller dimensions than the ball and cone used for the measurement of the hardness. Whether or not this is of importance depends largely on the structure of the material. Taking, for example, such a material as phosphor bronze, we have there a soft copper matrix with extremely hard spots of copper phosphide. Whether the Brinell hardness test would give any idea as to the hardness of such a material is by no means certain. In cast iron and associated products we have likewise a ferrite matrix with carbon either alone as in gray iron or variously combined with iron as in pearlitic iron. In gray iron where the carbon is graphitic it is much softer than the matrix, in pearlitic iron somewhat harder, and in white iron, where it is in the form of cementite, it is extremely hard. None of the hardness tests, however, gives any indication as to whether the measurement represents a hardness of the matrix or of the embedded elements, or of the true average between the two.

Analyzing Machine-Shop Problems for Economy

(*Continued from page 338*)

is desirable for the reasons given heretofore and also because present conditions make any method desirable which substitutes machines for men.

That there is little or no final economy in a complete combination of all operations does not prove that there can be no economy in the combination of some of them. In the case here considered it would seem, at a first glance, that there should be some advantage in the simultaneous drilling (and also reaming, if reaming is done at all) of the two main holes. In fact, the comparison made above was between the complete machine and single operations, some of which had already been combined.

If every operation had been done singly, the final result would have been much more in favor of the turret machine. However, before deciding that such a machine should be built, it would have been necessary to consider various partial combinations and the final result would have been the same.

An analysis of this kind may appear to be a slow and tedious bit of work, but when a factory must give up a considerable part of its floor space and a number of machines and tools for the manufacture of a single piece, and in addition provide a number of men, the management is not justified in selecting a mode of procedure unless it has tested out, at least on paper, all possible combinations. A few days are well spent on such a task. That various factories employ radically different methods to obtain the same result is prima facie, if not conclusive, evidence that such an analysis is not always made and that so-called "judgment," which might more properly be called guesswork, has taken its place.

Interest on Savings Should Be Considered in Figuring Costs

In estimating the cost of the special machine first cost and nterest were both figured, and this is proper, because if the machine had not been built, the fund used for the machine would have been bearing interest through all the years of the life of the piece. On the other hand, if we consider the savings made by the use of such a machine as capital returned to the business, this capital also would be bearing interest.

Where the life of the piece is long the item of interest becomes of considerable importance. As an example, a case will be assumed where it is estimated that special machinery costing $1000 will produce savings of $2000 per year; and where the life of the piece is estimated to be 10 years, without considering the interest on the savings, we would find the following conditions:

First cost	$10,000
10 years' interest at 6 per cent	6,000
Total cost at end of 10 years	$16,000
Saving per year	$2,000
Total savings at end of 10 years	$20,000
Profit	$4,000

This is too small a profit to justify the purchase of the special machine. However, the balance sheet looks different when the interest on savings also is considered, as it should be.

The total interest on the savings is the interest for 1 year plus that for 2 years, etc., up to the interest for 9 years. This total equals the interest on $2000 for 45 years and amounts to $5400, so that the total profit is not $4000 but $9400, and this may well be enough to justify the purchase of special equipment.

International Annual Tables and International Critical Tables

THE Annual Tables of Constants and Numerical Data, Physical, Chemical, and Technological, published under the authority of the International Union of Pure and Applied Chemistry through an international commission created for the purpose, contain all the numerical data—physical, chemical, engineering, metallurgical, biological, etc.—published anywhere in the world during the past year. Full literature references and method of measurement are also given. These data are collected in the various countries of the world by national committees of abstractors who examine carefully, page after page, all of the publications of the country which are at all likely to contain such data.

Annual Tables are edited and published in Paris. Their contents are complete but non-critical, all data published being reported as published. They are supported by an international budget raised by contributions from the governments and the scientific and engineering societies of the various countries of the world. Their annual publication was interrupted by the war, but after the publication of Volume 5, now in process, annual publication will be resumed.

The American representative on the International Commission in charge of Annual Tables is E. W. Washburn. The American agent for the Annual Tables is the Chicago University Press.

The International Critical Tables of Numerical Data of Physics, Chemistry, and Technology differ materially from the Annual Tables since they will constitute a critical assembly of all existing knowledge on the subject, the values of the various constants and properties which they are to contain being those selected by experts after a critical examination of all data available in the literature. It is estimated that about three years will be required to prepare these tables for publication. It is hoped to publish revised editions at intervals of perhaps ten years.

It will be seen that Annual Tables and Critical Tables supplement each other, Annual Tables serving for the collection of data during the periods between revisions of Critical Tables and also serving as the raw material for the experts who prepare Critical Tables.

The publication of International Critical Tables is supported by funds derived principally from industrial organizations. They will be published under the authority of the International Union of Pure and Applied Chemistry and the International Research Council. The financial and editorial responsibility lies entirely in American hands and the Tables will be published in the United States with English as the principal language.

Correspondence

CONTRIBUTIONS to the Correspondence Department of MECHANICAL ENGINEERING are solicited. Contributions particularly welcomed are discussions of papers published in this journal, brief articles of current interest to mechanical engineers, or comments from members of The American Society of Mechanical Engineers on activities or policies of the Society in Research and Standardization.

Engineering Society Activities in India

TO THE EDITOR:

As a member of the Society and so far as away from home, it has seemed to me that a news item in a few notes for MECHANICAL ENGINEERING might be acceptable and interesting to the membership.

India is a country toward which more attention will be paid by the outside world in future years. Its wonderful natural resources coupled with the awakening of its people to greater commercial and industrial activity, it is hoped, will bring about greater prosperity. England has a great problem on her hands. The insistent demands placed upon her by the Indian people of both a conservative and radical character make conservative legislation difficult. A working together of all factions will maintain order and prosper the great industrial enterprises and large engineering efforts now completed or under construction. There are many reasons for a feeling of confidence for the future, but they are too extensive to write out here. Let it suffice to write that England would not start new projects of extensive character were she without that confidence.

A past record of engineering and industry has brought about a most natural demand for an engineering society of a nature similar to the A.S.M.E. but of necessity concerning the three major branches, namely civil, electrical, and mechanical, with membership allowed to any engineer who has shown the requisite qualifications. This demand has been met by the organization of the Institution of Engineers (India).

I am very pleased to report the courtesy extended to me to attend their fourth annual meeting Feb. 4 to 7, inclusive, in Calcutta. The program, copy of which is enclosed, was a very interesting one indeed. Comments upon the different subjects presented would take up too much space; but the dinner and visits need a word. The principal guest at the dinner was the Governor of Bengal, who spoke on the same day that Mahatma Gandhi was liberated from prison near Bombay on account of ill health—two men very much in the public eye, both seeking ways and means of forwarding India's industrial and economic position, but in very different ways. The trips were to the Cossipur power station where the largest steam turbine in India is located—15,000 kw.; and King George's Dock Scheme, the largest inland project of its kind in the world, to relieve congested traffic on the Hooghly River 100 miles in from its mouth. (South of Bombay a new hydroelectric project of 150,000 kw. total capacity will soon be under way.)

The membership of the Institution is of a high standard, selected on a basis similar in many respects to that in use by the A.S.M.E. There are at present all over India 657 members, a good showing for a society of but a few years' standing. Progressive action in the location of branches in important Indian centers has taken on new life. A comparatively new society in a very old country backed by leading engineers will, I hope, some day have a mutually helpful influence when engineering societies over the world have their international relations just as England and America have started to do.

R. A. PACKARD.

Chengail, India.

[In addition to the dinner and excursions mentioned by Mr. Packard, the program to which he refers included papers indicative of the varied activities of the Institution. These dealt with Einstein's theory; the politics of subsoil water; the congestion of Calcutta; the 1924 Indian boiler regulations; Indian sewerage practice; and with working costs in small power plants.—EDITOR.]

Forces Acting on Ball-Bearing and Roller-Bearing Connecting Rods

[A communication from Mr. N. K. Stitt on the above subject appearing in the April issue of MECHANICAL ENGINEERING has aroused considerable interest, and has been commented on in letters from Messrs. F. A. Jimerson and Channing Turner in the May issue. Excerpts from further correspondence on the same subject are published below.—EDITOR.]

TO THE EDITOR:

Mr. N. K. Stitt is unquestionably right in stating that the crank pin rotates and the connecting rod oscillates. These motions, however, are relative to the frame of the engine or any other *fixed member*. Relative *to each other*—and this alone determines the effect on the ball bearings—the motion, as shown in Fig. 1, is one

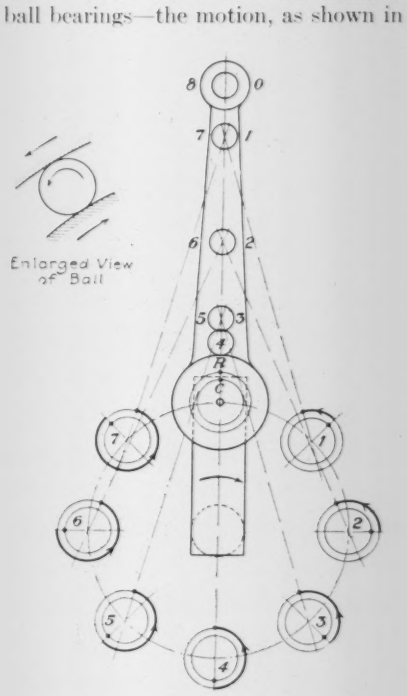

FIG. 1 DIAGRAM TO SHOW THAT THE MOTION OF A CONNECTING-ROD STRAP RELATIVE TO THE STRAP IS ONE OF PURE ROTATION

(*R* is a fixed point on the connecting rod and *C* a fixed point on the crankpin. The heavy arrow shows the amount of relative motion of *R* with respect to *C* at each successive position of the crank.)

of pure rotation of the connecting-rod strap around the crankpin, in a direction opposite to that of the rotation of the crank relatively to the frame. True the angular velocity of this rotation is not uniform throughout one revolution, due to the angularity of the connecting rod, but the effect of this oscillation is merely to make the instantaneous velocity of rotation slightly greater or less than the average for one revolution without, however, ever causing a *reversal* of direction of the relative motion of the connecting rod and the crankpin or even a momentary stoppage of this motion. The balls, therefore, if running in properly designed races, should rotate freely in one direction and there should be no cause for slippage.

In the conditions illustrated in quadrants 3 and 4 of Mr. Stitt's sketch, there could not be slippage in any amount unless there were a third force acting to hold the ball stationary while the two surfaces slid past it. In other words, the two forces which he illustrates would merely cause the ball to have a motion of translation in the same direction as that of the contingent surfaces and any difference in magnitude of the velocities of these two surfaces would impart an additional motion of rotation to the ball; but

two tangential surfaces alone on a ball *cannot* cause sliding of the ball over either one of them.

Of course, since the connecting-rod thrust is always longitudinal the wear on the outer race will be most severe at one or two points, causing unequal wear on this race which may in time bring about its deformation. I think a more probable explanation of the flattening of the balls noticed by Mr. Stitt is the shock due to the sudden application of the forces, particularly in internal-combustion engines, and in an air drill this would be even more severe. It would seem that bearings providing substantially point or line contact, as do balls or rollers, might not be as well adapted to resist shock loads as plain bearings where the concentration of force is consequently less, but there are installations, such as the wheel bearings of automobiles, where balls and rollers stand up under severe shocks for long periods.

CARL W. VAIL.

Rutherford, N. J.

TO THE EDITOR:

In his illustration of quadrants 4 and 3 Mr. N. K. Stitt makes it appear that the ball is constrained to roll at the same time in opposed directions, causing slip. Your correspondent overlooks the fact that the motion of the ball is not one of revolution only, but one of progression also. To illustrate:

In Fig. 2 (*a*), if block *A* and block *B* move in the same direction, at the same speed, the ball *C* will not change its position in relation to *A* and *B*. However, if the speed of advance of *A* is greater or less than that of *B*, ball *C* will not only revolve but will travel along with the faster-moving block over the surface of the slower-moving block, and fast enough to compensate for the difference in surface speed of the two blocks.

In Fig. 2 (*b*), if *A* and *B* move in opposite directions at the same speed, ball *C* will revolve at the surface speed of the blocks. If either *A* or *B* accelerates, then ball *C* will advance with the faster-moving block at a surface-position advance proportionate to the difference in surface speeds.

In Fig. 2 (*a*) the ball revolution starts when the speeds of *A* and *B* are different and it will roll along the slower-moving block to compensate for the difference in surface speed of the two blocks.

In Fig. 2 (*b*) the ball revolves proportionally to the speed of the blocks, but its advance is along the surface of the slower-moving block in the direction of the faster one to compensate for the difference in surface speeds. This is as true when the surfaces are the raceways of a ball bearing as it is when the curved surface is developed into straight lines; there can be no slip between a ball and two contacting surfaces, regardless of the direction of their motion.

The two rings of a ball bearing can be revolved together or the direction can be reversed, the speeds can be constant or they can differ in any degree, but the ball revolution and its advance along the slower-moving surface are always in step.

The bearings which in Mr. Stitt's experience developed square balls were either loosely fitted, allowing pounding at the peak loads, or they were not large enough to stand the service required, and broke down from excessive fiber stress.

H. REYNOLDS.

New Britain, Conn.

TO THE EDITOR:

Referring to Mr. Tawresey's letter, I agree with him that the centrifugal force acting on the retainer is probably in most cases the deciding reason when anti-friction bearings with retainers, supported by the rolling elements, give trouble.

This effect of the centrifugal force is, however, well known to ball-bearing engineers, while the effect of the speed variations of the rolling elements, described in the communication from Mr. N. K. Stitt has, to my knowledge, never been pointed out before, and his article has thus the merit of novelty.

I take exception to Mr. Tawresey's contention that Mr. Stitt's ideas are fallacious in their fundamental principles and consider it a simple matter of mathematics to determine whether, and to what extent, the effect of the angularity of the rod is negligible as compared to the influence of the centrifugal force.

The effect of the centrifugal force, described by Mr. Tawresey, has been overcome by the use of the "located" retainer, but the effect of the speed variations has, to my knowledge, not been realized heretofore, nor has any means been suggested which will overcome this action.

OSCAR R. WIKANDER.

New York, N. Y.

TO THE EDITOR:

The argument advanced by Mr. N. K. Stitt is untenable since it is based on erroneous theory and at the same time not in accord

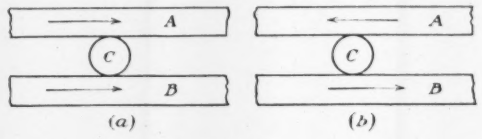

FIG. 2 DIAGRAMS TO ILLUSTRATE ACTION OF A BALL BETWEEN TWO PLANE MOVING SURFACES

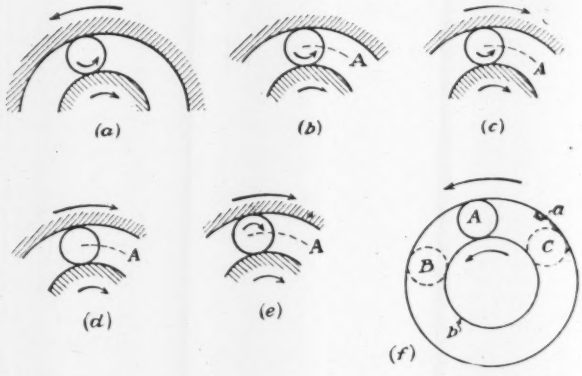

FIG. 3 DIAGRAMS TO ILLUSTRATE ACTION OF A BALL BETWEEN TWO CIRCULAR MOVING SURFACES

with the observed facts. The circumstances which he relates do not by any manner of means prevent true rolling. Slippage would not be introduced except in extreme cases of acceleration which introduce the additional factor of inertia. While it is true that the balls and retainer element are subject to alternate acceleration and retardation as a result of the varying angularity of the rod, this effect is negligible compared with the predominating influence of centrifugal force.

It has been conclusively demonstrated that the abrasion observed on the balls or rollers of the ordinary type of bearing in this service results from excessive radial pressure at the retainer contacts. This suggested the employment of a "located" type of cage in order to support its centrifugal reaction independently of the ball contacts. The "located" cage rides on the lands of either the inner or the outer race and thus provides a very substantial area of support. The prongs or separating elements of the retainer are then subjected only to the individual components of the centrifugal ball loads and the retainer is accordingly relieved of their cumulative effect.

The correctness of the principle of the located cage is fully attested by the results which have been obtained in actual service. It has also been successfully applied in similar types of application, such as planetary reduction gears, where the planet-gear bearings are subjected to high centrifugal forces.

J. S. TAWRESEY.

New Britain, Conn.

TO THE EDITOR:

Mr. N. K. Stitt attempts to show that at certain phases of the rotation of the crank the crankpin and strap of the connecting rod will rotate in the same direction with the strap moving at a higher rate of speed than the pin, thereby causing the ball to tend to rotate in two directions at once. This he assumes would necessitate "slipping" of the ball on one surface or the other during that phase of rotation. One hundred and eighty deg. further in advance, he asserts, this condition would again exist, thus making two periods of slip during a revolution of the crankshaft.

Consideration of a few fundamentals will demonstrate the error in the foregoing conclusion.

Suppose we have two flat pieces of metal with a ball or roller placed between them. If the two pieces are now moved at *equal* speeds in opposite directions the ball will *simply rotate on its axis*. If the upper one is held stationary while the lower one is moved the ball will rotate on its axis as before, but in rotating it advances in the direction in which the lower piece moves. There is no slip of the ball, purely a rolling-motion.

Again, move the two pieces both in the same direction but move the lower piece faster than the upper one. The ball will again move in the same direction without slip or interruption of perfect rotation.

The sketches shown at (*a*), (*b*), and (*c*) of Fig. 3 correspond to the three above-mentioned cases, except that the pieces which were flat have now been bent to a circular, concentric form. This new form, however, does not change the principles involved.

Assume now that the pieces are rotated in the same direction at the same number of revolutions per minute, as at (*d*), Fig. 3. The ball in this case simply remains stationary and serves as a distance piece. It does not rotate on its axis nor does it slip. Now assume that a greater speed is given to the outer race as at (*e*). The ball begins to rotate on its axis without any slip while moving in the direction of *A*. Taking the bearing shown at (*f*), and keeping in mind the previous sketches shown, it is readily observed that if the inner piece were rotated at a given speed which would give to the surface *b* the same speed at which the surface *a* of the outer race were traveling, but in opposite directions, the ball would rotate at *A* on its axis without slip or travel in either direction. Now when the speed of one race or the other becomes greater or less than the speed of the other race, the ball simply changes its direction of rotation. If the two races are moving in the same direction, the axis of the ball moves in the same direction but at a greater or less rate of travel, depending on the difference in the speeds of the races. There is no possibility of having any slip between two moving surfaces having a sphere or series of spheres interposed between them.

There is therefore no reason to suppose that a connecting rod or any other part in which a ball bearing may be employed can fail because of slip of the nature of that indicated in Mr. Stitt's letter. There is probably a certain amount of "slip" in any ball bearing which is due to wear of the balls or to "spinning" of the balls, but this is insignificant.

WILLIAM V. FITZGERALD.

New York, N. Y.

A.S.M.E. Boiler Code Committee Work

THE Boiler Code Committee meets monthly for the purpose of considering communications relative to the Boiler Code. Any one desiring information as to the application of the Code is requested to communicate with the Secretary of the Committee, Mr. C. W. Obert, 29 West 39th St., New York, N. Y.

The procedure of the Committee in handling the cases is as follows: All inquiries must be in written form before they are accepted for consideration. Copies are sent by the Secretary of the Committee to all of the members of the Committee. The interpretation, in the form of a reply, is then prepared by the Committee and passed upon at a regular meeting of the Committee. This interpretation is later submitted to the Council of the Society for approval, after which it is issued to the inquirer and simultaneously published in MECHANICAL ENGINEERING.

Below are given interpretations of the Committee in Case No. 436, as formulated at the meeting of February 7, 1924, and in Cases Nos. 437, 438 and 439, inclusive, as formulated at the meeting of March 14, 1924, all having been approved by the Council. In accordance with the established practice, the names of inquirers have been omitted.

CASE NO. 436

Inquiry: What thickness is required for saddles or frames to be fitted inside of dished heads, when the manholes are 11 × 15 in., and the frames are designed for two rows of $^{7}/_{8}$-in. rivets, for a working pressure of 250 lb., used in dished heads of dimensions varying from $^{45}/_{64}$ to $^{55}/_{64}$ in. thick, and 36 × 48 in. radius of dish?

Reply: It is the opinion of the Committee that the thickness of the plate for the saddle or frame shall at be least that called for by Par. 195 of the Code for a dished head with a manhole opening. The saddle or frame shall be attached to the dished head in accordance with the rules under Pars. 259 and 260.

CASE NO. 437

Inquiry: What maximum allowable working pressure is permitted under the Heating Boiler Section of the Code for copper tubing to be inserted in the form of coils or loops in the fireboxes of steel heating boilers for the heating surface? It is pointed out that there is no reference in the Heating Boiler Section of the Code to pipe or tubing material of copper.

Reply: In Par. H-14 of the Heating Boiler Section of the Code specifying minimum thicknesses for tubes for use in water-tube and fire-tube boilers, only tubes made of steel or iron were considered. Where heating boilers are to be constructed using copper tubes, either straight, bent or coiled, it is the recommendation of the Committee that the following minimum thicknesses should govern:

In water boilers where working pressures of over 30 lb. and not to exceed 160 lb. per sq. in. may be used:

$$t = \frac{D}{30} + 0.03$$

where t = thickness of tube wall in in.
D = outside diameter of tube in in.

For steam boilers to be used at pressures not exceeding 15 lb. per sq. in., and water boilers where the maximum allowable working pressure does not exceed 30 lb. per sq. in.:

$$t = \frac{D}{45} + 0.03$$

the definitions of the letters being the same as above. In no case shall a tube thinner than No. 16 gage (B. W. G.) be used.

CASE NO. 438

Inquiry: Are the Recommendations for Repairs by Welding, which appear in the Appendix of the 1918 Edition of the Boiler Code, optional or mandatory?

Reply: It has been the idea of the Boiler Code Committee from the beginning that the Appendix is explanatory of the Code and contains matter which is not mandatory, unless specifically referred to in the Rules of the Code.

CASE NO. 439

Inquiry: Is it intended that only steel having a range of tensile strength of 45,000 to 55,000 lb. per sq. in. shall be used for joints welded by the forging process? If it is permissible to use a steel having another range of tensile strength, can the working stress of 28,500 lb. per sq. in. be used?

Reply: Par. 186 requires that all joints welded by the forging process, if to be allowed the ultimate strength specified of 28,500 lb. per sq. in., must be made with steel plates having a range in tensile strength of 45,000 to 55,000 lb. per sq. in. Attention is called, however, to the fact that in the recent revisions of the A.S.M.E. Boiler Code it has been proposed to increase the ultimate strength allowance for forge-welded joints from 28,500 lb. per sq. in. to 35,000 lb. per sq. in. This paragraph as it has been proposed for revision will read as follows:

> "*Welded Joints.* The ultimate strength of a joint which has been properly welded by the forging process, shall be taken as 35,000 lb. per sq. in. with steel plates having a range in tensile strength of 45,000 to 55,000 lb. per sq. in. Autogenous welding may be used in boilers in cases where the stress or load is carried by other construction which conforms to the requirements of the Code and where the safety of the structure is not dependent upon the strength of the weld."

MECHANICAL ENGINEERING

A Monthly Journal Containing a Review of Progress and Attainments in Mechanical Engineering and Related Fields, The Engineering Index (of current engineering literature), together with a Summary of the Activities, Papers and Proceedings of

The American Society of Mechanical Engineers

29 West 39th Street, New York

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Standardization of Machine Tools

IMMENSE strides have been made both in engineering and in the art of machine building in the last generation. One of the most significant tendencies of this time has been the trend toward standardization with its contribution to greater production and the consequent greater benefit to the ultimate consumer, mankind.

Standardization cannot be arbitrary. This is especially true in the machine-tool industry and a large amount of attention must be given to all phases of the subjects that are affected by such standardization, as well as to the extent of the changes necessary from present practice. While the latter is not always right or ideal, it has nevertheless established its utility generally and must be the starting point for standardization.

That machine-tool standardization would be a great contribution to national productivity and economy has long been recognized by The American Society of Mechanical Engineers and the National Machine Tool Builder's Association. Under the procedure of the American Engineering Standards Committee they have now organized a Sectional Committee on the standardization of Machine Tool Elements and Small Tools, consisting of representatives of machine-tool builders, machine-tool users and of engineers engaged in machine-tool and small-tool construction and use.

Some standardization in this field has already been effected. The engineering departments of large manufacturers have been accustomed to draw up their standard specifications and have compelled tool suppliers to conform to these standards on all machinery and tools that they purchased, with resultant economies within their organizations. On the other hand, the suppliers of small tools have attempted to standardize their product for interchangeable use in the machines of various builders.

However, it has been recognized that individual standardization is only a small step in the right direction, and that the only form of standardization of small tools and machine-tool elements that will be of universal value to the maker, distributer and user is a national standardization which will be acceptable to engineers and tool users. Such standardization is by no means a small undertaking. However, the virile way in which the joint committee with its sub-committees is taking hold, promises valuable results within a reasonable period of time.

This standardization should prove of immense value to the manufacturer of machine tools in simplifying drawings, patterns, replacements, gages, steel, tools, etc., and in releasing many of those now very rare employees, "experienced all-around machinists," for more important work. The user's benefits are fully as great when he buys a standardized tool, for he knows that it will use the standardized equipment he already has in his plant; he knows that when he buys a machine of a certain type he will not have to duplicate the tool equipment he already possesses.

Standardization in this field is practicable. It has already been worked out successfully in a great many cases along other lines, and improved efficiencies and lower costs have resulted.

The number of small and useless variations now existent in machine-tool elements and small tools is probably beyond the comprehension of even a skilled engineer, and it is not to be expected that this joint committee's first recommendations and standards will be final in all particulars; they will, however, be valuable in that they will furnish a starting point for further standardization. The Committee will take up the entire field of machine-tool elements and small tools, including lathes, upright drills, planers, boring mills, turret lathes, shapers, milling machines, grinding machines, punching machines, slab milling machines, hacksaws, etc.; and such elements must be considered as swing, distance between centers, nose thread tapers, tee slots, length, width, heighth, tool holders, length of stroke, adjustments, capacity, clamps, bolts, vises, dies, jigs and fixtures, gages, etc. Obviously it will be impossible to accomplish this work without a great deal of research and consideration of general usage throughout the country, and the principle that the tortuous cow path of today may be the crooked highway of tomorrow may not in all cases be avoided.

An effective start has already been made in the standardization of tee slots and holding bolts. A sub-committee has been appointed and its tentative report will be forthcoming shortly.

H. E. HARRIS.[1]

Engineering News-Record Celebrates Its Fiftieth Anniversary

FIFTIETH birthdays are rare occasions among American technical journals. On April 17, 1924, our forward-looking contemporary, *Engineering News-Record*, celebrated the semi-centennial of its birth by issuing an anniversary number in which distinguished contributors surveyed the developments in the various branches of civil engineering during the past half-century.

Engineering News-Record can regard its past with satisfaction and its future with confidence. Its record of accomplishment is noteworthy, and its place in the technical field established and assured. Although popularly regarded as specializing in the field of civil engineering, the entire profession looks to it with confidence to inspire, through its pages, men to its avowed ideal of the great opportunity that the next fifty years offer the engineer—"the opportunity to contribute to social and economic reform that respect for basic truth and the undeviating deduction from the truth that the past training and practice of the engineer make him so well able to supply."

CALVIN W. RICE,
Secretary, A.S.M.E.

Dr. Mead—An Able Engineer and Administrator

THE principle that governmental engineering projects shall be executed by engineers rather than by politicians has been recognized by Dr. Work, Secretary of the Interior, in the appointment of Dr. Mead as Commissioner of Reclamation. This is a victory for the American Engineering Council and The American Society of Civil Engineers who fought for this principle when they requested a complete hearing for Arthur P. Davis after he was dismissed as Director of the Reclamation Survey. Dr. Mead's appointment has been heralded widely by engineers and agriculturists and has received the hearty approval of Mr. Davis; and as regards the public, it has done something to offset the reflections cast upon the engineering profession by the latter's dismissal.

[1] Chairman of the Central Committee on Standardization of Small Tools and Machine Tool Elements, American Engineering Standards Committee.

Heat-Transfer Symposium of the American Chemical Society

AT THE recent meeting of the American Chemical Society in Washington two days were devoted to the presentation of papers on the important subject of heat transfer, abstracts of which will be found on pages 349–351 of the Survey of Engineering Progress in this issue.

Two facts brought out particularly appealed to those present. The first was the tremendous consumption of fuel by the chemical industries, which made the question of economy in the use of combustibles of sufficient importance to attract the special attention of operating engineers. It was a revelation to all those who had not followed the amazing development of the American chemical industries since the beginning of the war. For example, one concern requires as much as 200 carloads of coal a day, and as a matter of fact the chemical industry as a whole is rapidly becoming one of the largest consumers of fuel in the country.

The American chemical industry was only in its swaddling clothes when the war started. With the German industry out of the way as a competitor it rapidly grew and for a while was in a position to dictate its own terms to the market.

In the first years of the war and immediately thereafter all that could be produced could be sold, and the traffic was expected to bear all the prices that could be loaded on it. In the last few years, however, the bars keeping out foreign competition have been let down in places and there has also been a considerable amount of competition among domestic producers themselves, so that in the chemical industries as elsewhere it is a case of the survival of the fittest—and the fittest means those who can utilize their raw materials with the greatest efficiency. Hence the great and healthy interest of chemical engineers in fuel economies and, as a result, in the phenomena of heat transmission.

The other feature which becomes apparent from reading the papers is a further illustration—and they often brought out at engineering meetings—of the all-too-frequent unreliability of various coefficients found in our textbooks and engineering handbooks. There have been a few investigators like Regnault who have secured correct measurements, with extremely crude equipment but it would appear that the majority of investigators in the past have given results which are sadly lacking in accuracy. At the meeting under consideration several such generally accepted values—for example, those for heat transfer in evaporators—were shown to be inadequate and were replaced by new values which are probably sufficiently correct to stand for a long time.

American Engineering Council Committee Reports On Muscle Shoals Situation

THE questions involved in the disposition of Muscle Shoals and the problems relating to its proper development for the greatest benefit to the country were recently taken up for consideration by a committee of the American Engineering Council at the request of Senator Norris, Chairman of the Senate Committee on Agriculture. This committee was made up of Fred R. Low, President A.S.M.E., Harold W. Buck and Dr. Leonard Waldo of New York City, Dr. H. E. Howe of Washington, E. B. Whitman of Baltimore, J. B. Davidson of Ames, Iowa, and Prof. H. B. Walker of the Manhattan Agricultural College, Manhattan, Kan.; and the report which it addressed to Senator Norris reads as follows:

Pursuant to your request under date of April 5, relative to the Muscle Shoals situation, the American Engineering Council appointed a committee to examine the available data and facts and report thereupon.

The committee so appointed found it impossible in the time available and with the means at its command, to sift out from the mass of conflicting testimony and information, sufficient undisputed and determinable data upon which to base a sound engineering recommendation as to the disposition or use of the property.

The committee was, however, unanimously agreed:

First, that a Joint Committee of Congress should be constituted "to consider offers, conduct negotiations and report definite recommendations" as advised by the President in his message to Congress delivered December 6, 1923.

Second, that no disposal should be made of any of the Muscle Shoals properties or rights until each Joint Committee of Congress shall have rendered its report.

Third, that in no event should any disposition of the power plant be made that is not in substantial accord with the provisions of the Federal Water Power Act.

In the course of its investigations the committee found nothing to justify the popular belief that the operation of the existing plants at Muscle Shoals will make substantially cheaper fertilizers immediately available, inasmuch as nitrates, however important, constitute but one of the three basic ingredients of commercial fertilizers, and consequently a considerable reduction in the nitrate cost would be reflected only to a slight degree in the cost of the marketable product.

The committee further found that recent developments of the synthetic process of nitrogen fixation had materially changed the entire outlook in the art and it is now quite possible that this process, for the use of which the so far unsuccessful Muscle Shoals Plant No. 1 was designed, may yet yield nitrate at a cost to compete with that obtained from Chile; and Plant No. 1, until recently considered a failure, may be the more valuable of the two constructed by the Government.

The Administrative Board of the American Engineering Council has carefully reviewed the work of its committee and endorses the findings and recommendations above set forth; and in view of the great importance of the questions involved and the much apparently contradictory information thereon presented to the Congress and to the public, the said Board would recommend, and as far as propriety permits, would urge that no disposition of the plants be decided upon until a thorough investigation can be made by a disinterested technical commission and the Board hereby tenders its services to assist in the formation of such a commission if and whenever such assistance may be desired.

Gages Vital to Industrial Preparedness

INDUSTRIAL PREPAREDNESS as a guarantee of peace is a tremendous problem with many ramifications. The May-June issue of *Army Ordnance*, the organ of the Army Ordnance Association, which is devoted entirely to the subject of gages, is a definite indication that the Ordnance Department appreciates the fundamental importance of this most troublesome ramification. Colonel John Q. Tilson, member of Congress from Connecticut, in the leading article of the issue in question, points out that the solution of this problem "is a work that can best be done in time of peace. A thorough study should be made of every essential component of materiél. Those necessitating the use of considerable gage, jig, and fixture equipment, involving long time and special mechanical skill in manufacture, should be given priority of consideration. The goal should be an adequate reserve of such equipment, kept well up to date. Nothing short of this will satisfy the proper demands of a great country which is entitled at all times to a reasonable degree of preparedness for its own defense."

International Conference of Women Engineers

THE Second International Conference of Women Engineers was held in Manchester, England, the early part of April, with forty delegates in attendance, including representatives from America and Belgium. The presidential address on the opening day of the meeting, by the Hon. Lady Parsons, President of the Women's Engineering Society, reviewed some of the outstanding engineering achievements of the year. An address of welcome was delivered by the Lady Mayoress of Manchester.

Some of the technical papers which were features of the meeting were Heavy Oil Engines—Present and Future, by Miss V. Holmes, (England); Resistance Welding, by Mrs. McBerty (America); and Les Alterno-Moteurs, by Mlle. Massart (Belgium). Visits were made to the spinning mill of R. Greg and Company at South Reddish, the Metropolitan Vickers Electrical Company, Ltd., the Barton Aqueduct, and the workshops and laboratories of the College of Technology. All lectures were open to the public.

The interest of the meeting to American engineers lies largely in the fact that in England women have already entered the engineering profession in such numbers that for the second year a conference has been successfully carried to completion.

A Correction

MR. EMMET has called our attention to the fact that a mistake in numbering was made in preparing the original drawings for Figs. 2 to 7 of his paper in the May issue of MECHANICAL ENGINEERING on The Emmet Mercury-Vapor Process. Figs. 2, 3 and 4 on page 236 should be numbered 5, 6 and 7 while Figs. 5, 6 and 7 on the same page should be numbered 2, 3 and 4.

Ambrose Swasey Receives John Fritz Medal

"For His Achievements as a Designer and Manufacturer of Instruments and Machines of Precision, a Builder of Great Telescopes, a Benefactor of Education, and the Founder of Engineering Foundation"

ON WEDNESDAY EVENING, April 23, in the Engineering Societies Building, New York City, the John Fritz Medal was presented to Ambrose Swasey of Cleveland, Past-President of The American Society of Mechanical Engineers for his achievements "as a designer and manufacturer of instruments and machines of precision, a builder of great telescopes, a benefactor of education, and the founder of Engineering Foundation."

Charles F. Rand, Chairman of the John Fritz Medal Board of Award, presided over the meeting. Addresses were made by Maj.-Gen. William Crozier, former Chief of Ordnance, U. S. Army; Dr. William Wallace Campbell, President of the University of California and Director of Lick Observatory; and Dr. John R. Freeman of Providence, who presented Dr. Swasey for the Medal.

General Crozier paid high tribute to Dr. Swasey as a designer and manufacturer of instruments of precision, so many of which were furnished for the use of the American Army during the World War. He spoke of Dr. Swasey as an engineer whose military services are worthy to rank beside those he has rendered the civil and scientific world.

The addresses of Dr. Campbell and Mr. Freeman appear in part below.

Address by Dr. W. W. Campbell

DR. AMBROSE SWASEY'S introduction to astronomy and astronomers occurred under unique and interesting conditions. In 1874, just 50 years ago, James Lick, a Pennsylvanian by birth and a Californian by adoption, gave to a Board of Trustees of the University of California the sum of $700,000, "to provide for the construction of a telescope larger and more powerful than any in existence, and a suitable observatory connected therewith."

The Trustees, charged with the installing of the telescope and observatory, entered vigorously upon their duties. They commissioned Prof. Simon Newcomb to visit all established makers of optical glass, lenses, and telescope mountings to secure data and advice which would guide them in deciding upon the size and kind of telescope to be constructed. At that time the reflecting type of telescope was held to be a failure; the 6-ft. Lord Rosse reflector in Ireland, and smaller reflectors, were decidedly limited as to their accomplishments. The final decision was in favor of a 36-in. refractor, but there were misgivings as to its complete success. Could such large pieces of glass be cast and annealed which would be uniform in composition, free from local defects, and not subject to internal strains? Would the two large lenses, supported only at their edges, sag at the middle under the influence of gravity, to such an extent as to spoil the star images formed by them? It was decided to run these risks. The making of the glass in the rough was entrusted to Mr. Chance of Paris, who lost many years through difficulties encountered, but who finally succeeded. The figuring and polishing of the glasses to their final form of lenses, and in combination constituting the 36-in. objective, were to be undertaken by Alvin Clark & Sons, of Cambridge, Massachusetts.

There remained the extremely important question of the mechanical mounting of the telescope. The Trustees invited tenders of designs and bids, and several firms in Europe and America complied. The list included the leading builders of telescopes and one recently established firm, Warner & Swasey, of Cleveland, Ohio, then unknown to astronomers. The several plans were given consideration by experienced astronomers and engineers, as befitted the high responsibility, and by unanimous decision of the Trustees the award went to Warner & Swasey. It is worth noting that theirs was the highest of all the bids, but their design was so clearly the best that the firm's inexperience in constructing telescope mountings was not permitted to influence the decision.

In due time, in 1888, the James Lick telescope was erected and put into commission. It was immediately satisfactory and successful in all of its parts and as a whole. In power and applicability it surpassed the expectations of astronomers everywhere. It immediately became, and for more than two decades remained, the leading astronomical instrument of its time. The bearings which guide its movements are so perfect that, although it weighs many tons, it can be swung easily from one position to another by hand; and a weight of 7 lb. on one end of it can be recognized as throwing it out of balance. For 33 years I have made personal use of it and my admiration for its design and workmanship has remained unabated. The instrument has been used through every good night in the last 36 years, save possibly half a dozen nights when the dome or some detail of the telescope mechanism was undergoing repair, and it works as well today as it did in 1888.

A great compliment was paid to Dr. Swasey and to the firm of Warner & Swasey seven years after the Lick telescope was put into use. Dr. George E. Hale was charged with the duty of installing the new Yerkes Observatory of the University of Chicago. Its principal instrument was to be a 40-in. refractor. He had visited the Lick Observatory in 1890, and the unqualified success of the 36-in. telescope there led him to place the contract for the 40-in. Yerkes telescope with Warner & Swasey. The completion and installation of this instrument occurred in 1897, and its performance through the succeeding 27 years has been splendid.

Since the inauguration of the 36-in. telescope in 1888 to the present time, a considerable number of medium-sized and large refracting telescopes have been established in America. Their lenses have been made either by Clark or Brashear, but their mountings have been supplied almost wholly by Warner & Swasey. Among the designers of mountings for the new refracting telescopes of his generation, Dr. Swasey is recognized throughout the civilized world as *facile princeps*.

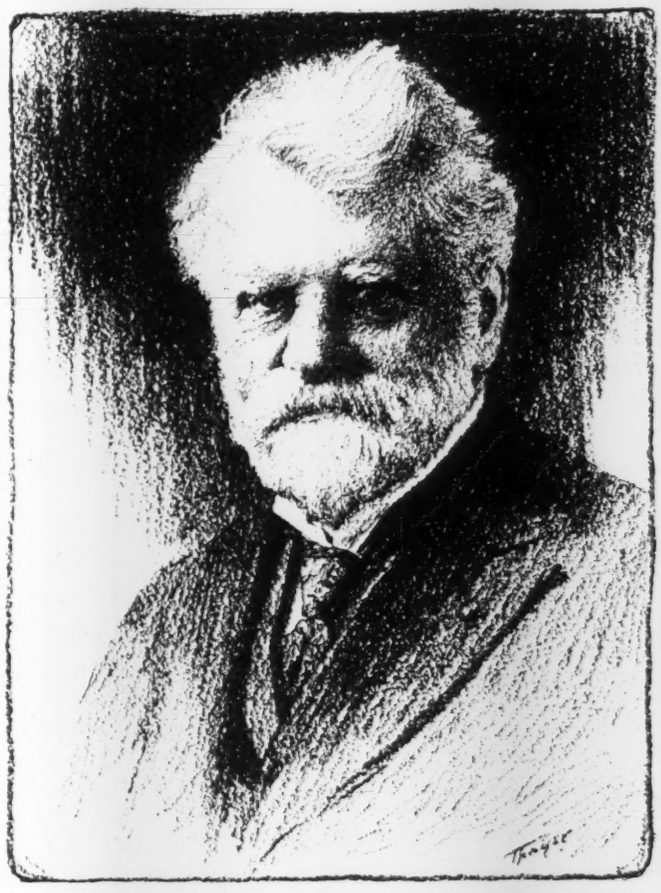
Up to the year 1899 reflecting telescopes, though existing in large numbers, especially in Great Britain, were regarded as not very successful. In the year mentioned, Keeler, then at the Lick Observatory, by virtue of his phenomenal success in photographing the nebulae with the Crossley reflector, worked a complete revolution in astronomers' point of view concerning the merits of reflectors. Forward-looking observatories became ambitious to possess them. The 60-in. reflector of the Mount Wilson Observatory, successful from its completion in 1908 or 1909, fired the imaginations of astronomers concerning the unlimited possibilities of reflectors. A large lens can be supported only at its edge. As we increase its diameter the thickness of glass traversed by the rays of light increases, and the danger of flexure in the lens, under the influence of gravity, increases rapidly; whereas in reflectors the thickness factor does not enter at all, and the mirror support is at the back of the mirror and only in minor degree at the edge. There is evidence that for lenses, a diameter of forty inches is close to the safe limit. I do not expect to hear that any man of experience is seriously planning for a refracting telescope larger than the Yerkes 40-in.; whereas the making and the use of the 100-in. Mount Wilson reflecting telescope have seemed to offer no discouragement of a technical nature to the construction of still larger reflectors. The earlier reflectors were failures in a disappointing degree because their mountings were flimsy and poor. Their optical parts were not sufficiently stable with reference to each other, and their motions as a whole were too irregular. To overcome these defects the designers of reflecting telescopes have labored.

Five years ago Dr. Swasey as the chief designer and the Warner & Swasey Company as the builders installed the 72-in. reflecting telescope, with covering dome, at Victoria, British Columbia, for the Dominion of Canada, and this instrument began at once upon a life of remarkable fruitfulness. The Warner & Swasey Company has in process of manufacture at this time the mountings and domes for the 60-in. reflector of the Argentine Republic and other large reflecting telescopes.

I have spoken of Dr. Swasey's success in the designing and construction of large instruments, which demanded originality, good

judgment, and perfection of workmanship. He has ventured into an even more difficult field. There is an instrument widely used by astronomers in observing the extremely accurate positions of the stars on the celestial sphere, known as the "meridian instrument," or "meridian circle." It carries two circles, usually about thirty inches in diameter, graduated by engraved lines to every two minutes of arc, or by 10,800 engraved lines in the 360 degrees of each of the two circles. The accurate placing of the graduation lines upon the circles is an exceedingly difficult and delicate matter. Not only must each group of, say, 30 or 60 or 90 adjacent lines be in its correct average position, within a small limit of error, but the intervals between successive lines must differ very little. The satisfactory graduating of such circles is one of the most exacting demands encountered by the makers of fine instruments. Dr. Swasey undertook the design, and his firm the construction, of a ruling machine, or dividing engine, as it is called, to do this work, and he met with a high degree of success. A Warner & Swasey meridian circle is in active service in the United States Naval Observatory, and results of the best quality are being obtained with it. The Warner & Swasey Company is the only firm which has essayed—and successfully—to compete with the two or three British and German makers of meridian circles of long standing.

Dr. Swasey has been honored many times for his good works. I do not attempt to list his honors. Two years ago he received the highest compliment which his peers have the power to pay him, through his election to membership in the National Academy of Sciences. Only a month ago he was on the Pacific Coast to receive the honorary degree of Doctor of Laws from the University of California, and a couple of days later, true to form, notwithstanding his 77 years, he motored to the summit of Mount Hamilton, through snow and a snow storm, for a visit of a few hours with his old friends in the "colony of astronomers."



AMBROSE SWASEY

In behalf of astronomy and astronomers I commend without reserve and in the highest terms the act for whose consummation we have this evening assembled, the presentation of the John Fritz Medal to Dr. Swasey.

Address by John R. Freeman

FORTY-FOUR years ago Ambrose Swasey was invited to succeed Prof John E. Sweet as instructor in the mechanical arts at Cornell University. Swasey at that time was a young man about 33 years old, who had become superintendent of the gear-making department of the great machine shop of Pratt & Whitney at Hartford, and had already become recognized as an especially skilful mechanic, possessed of knowledge, wisdom, and inventive talent.

It was many years ago that he told me of this, as one of the greatest surprises of his life—that he, a youngster without college training should be urged by a high college official to enter on this great opportunity, which he declined.

He modestly underrated his own ability and the breadth and value of the training to be had in those old machine shops where men found joy in good workmanship and that he received on his father's fine old New England farm.

Some of the most important lessons in engineering are taught outside college halls and Swasey, without knowing it, became a teacher, although he did not join the staff at Cornell.

Once at the home of James A. Hartness I noted three portraits on the wall of his study and asked why they were there. He replied that it was because they were three of the greatest teachers he had known, although not one of them was a college man.

"One," he said, "had taught by successful example the waste of useless competition; another had taught by example the value of standardization and that a shop should concentrate on the fewest possible sizes and varieties of product; the third had taught that in the industries one should experiment continually because in so doing you are more likely to run across the path to a useful idea."

I had the good fortune to know John Fritz, and have known intimately our medalist of the evening for nearly forty years. I have known or have met personally nearly all of the recipients of the John Fritz medal, and among them all I have never known a better teacher, by example, of a wise philosophy of life than the medalist of tonight.

A long time ago, when we were spending an evening together, he remarked, "Warner and I have made an important decision today. We have decided not to enlarge our works. Our young men and our associates urge that we can sell double the number of machines that we are now making. Probably that is true; but if we double the shop, what would become of us? We no longer would be cheerful on top of our job, but bowed down beneath its burdens. As things are now, we have the leisure to satisfy our individual fondnesses for fine mechanism, leisure to travel, to look about us, to pass some time with our friends, and to really enjoy the good things of life."

Distrust of bigness and faith in accuracy is only one of the great lessons which he and his partner have been teaching. That was a lesson more particularly for the older men. But they have taught a lesson also for the younger men in how to draw the line in our great engineering societies between helpful interchange of ideas and commercialism. In the nearly forty years that I have been meeting these men in our engineering societies, never have I heard either say a word in praise of the product of his own workshop. They have taught the young men that the technical society is not, properly, a salesroom.

Meanwhile, our friend has brought into the Society always the spirit of service, and has helped to make plain that the words which one can give in friendly counsel outside the sessions may be quite as useful as discussion on the floor.

Another lesson which our medalist of the evening has taught to larger audiences than he would have found at Cornell, is that the spirit of ideality can have its dwelling in a machine shop. Often as I have gone through the large works with him I have noted his fondness for the relatively small corner in which the astronomical instruments are made, or the small basement in which the most precise circular dividing engine in the whole world has its home. More than once I have heard him say, "Warner and I make our living out in the big shop, but this is the corner where we find our pleasure."

I heard Dr. Henry S. Pritchett, himself an astronomer of note, describe this rare pair as "men who got rich in building instruments for impecunious astronomers at less than cost," and after forty

years of observation I know that this is true, for our friend's riches are chiefly those of rare friendships.

Swasey has lived up to President Eliot's fine phrases of "finding joy in his work" and days full of the "durable satisfactions of life."

Speaking of the spirit of ideality in the machine shop, I have liked to think of John Fritz, of E. D. Leavitt, John C. Hoadley, Albert H. Emery, Henry Leland, Worcester R. Warner, and Ambrose Swasey as artists in the truest sense, working out their pictures, sculptures, or poems in cast iron, steel, or brass, rather than in marble, pigments, or words. These each have heard "the music of the spheres" and there they have dreamed and made their dreams come true. The greatest genius of all time, Leonardo, was no less an artist when he bridled fancies and thought out solutions to engineering problems than when he painted Mona Lisa.

At the time of Ambrose Swasey's seventieth birthday, which was about seven years ago, I had the good fortune to be his fellow-traveler in the Far East, with a number of others. It was a memorable tour. We became delayed on our itinerary, and Swasey was a bit blue over our non-arrival in Peking where he hoped to have a little celebration with friends to mark the passing of his seventieth milestone. The rest of us set out to have a birthday party right there in Seoul, the ancient capital of Korea.

Like most of those who travel we had been abashed occasionally by the importance of chief porters and hotel clerks, and it had been remarked that perhaps we would be received with more pomp and state if we had a great general or a duke in the party, and since Swasey looked the part, we once tried addressing him in front of the hotel clerk as "Baron Swasey," whereupon he became rebellious and spoiled the scheme. Therefore, without taking Swasey into our confidence, we concluded to make this birthday party the occasion of conferring a high title upon him with due ceremony. Antique royal garments were procured and our victim was kept guessing while clothed in a cloak that rivaled one of Uncle John Brashear's spectrums. Langdon Warner served as a reincarnation of one of the ancient kings, tall, with gorgeous robe, royal helmet, and a great state sword centuries old. He lectured the youth of seventy years upon the ancient history of his realm in verses that were wonderfully good, and as a proper finale, in giving the accolade said, "Rise, Sir Ambrose, Knight of the Kindly Heart."

Again, Ambrose of the Kindly Heart, in token of the appreciation, friendship, and love of many men, and by vote of a Board composed of eminently discreet judges of human nature as well as of "scientific and industrial achievement, I bid you rise to receive the John Fritz Medal."

An Engineer, Dr. Elwood Mead, Appointed Commissioner of Reclamation

THE appointment of Dr. Elwood Mead as Commissioner of Reclamation was recently announced by Secretary Work of the Department of the Interior. Dr. Mead replaces D. W. Davis, who was chosen as Commissioner by Secretary Work when the position of Director of the Reclamation Bureau was summarily abolished and A. P. Davis thus removed from control. By the appointment of Dr. Mead the federal reclamation activities are again placed in the hands of an engineer. Dr. Mead was professor of rural institutions at the University of California and until recently was chairman of the State Land Settlement Board. He has had a lifelong experience in irrigation administration, beginning as assistant state engineer of Colorado, then state engineer of Wyoming, then chief of irrigation and drainage investigations of the U. S. Department of Agriculture, chairman of the state rivers and water-supply commission of Australia, and consulting engineer of the Interior Department and of a number of countries in which irrigation is an important problem. Dr. Mead is a graduate in engineering and agriculture of Purdue University and of Iowa State College, a member of the American Society of Civil Engineers and other engineering bodies, and an honorary member of the American Society of Agricultural Engineers. Since last December he has been engaged with the Advisory Committee on Reclamation, reorganizing that service in the Interior Department, a report on which is pending. Dr. Mead's appointment has been heralded widely as one of the few instances in which the Federal Government has found the best man for the job.

Former Commissioner D. W. Davis becomes Director of the Finance Division of the Service, which will handle receipts and disbursements in a separate department from the engineering and agricultural divisions.

Former Director A. P. Davis was the guest of honor at a formal dinner in Washington on April 5, which was attended by more than 500 engineers, among whom were many of his former co-workers in the Reclamation Service. In the addresses, Secretary Hoover, former Secretary Garfield of the Interior, President Carl E. Grunsky of the A.S.C.E., and M. O. Leighton praised highly his long and successful period of public service. The event was staged by the Washington Society of Engineers and the District of Columbia Section of the A.S.C.E.

Col. H. M. Byllesby Dies

HENRY MARISON BYLLESBY, one of the foremost engineers in the electrical world and active head of a gigantic network of public utilities, died suddenly in Chicago, Ill., on May 1, at the age of sixty-five. He was born in Pittsburgh, Pa., on February 16, 1859. He was educated at the Western University of Pennsylvania and at Lehigh University, 1873–77, where he studied mechanical engineering. He was not graduated, leaving at the end of his Junior year. On the morning of his death he received word from the president of Lehigh, advising him that the faculty, by unanimous vote, had decided to award him a degree in mechanical engineering for his engineering accomplishments.

During his early career Colonel Byllesby was closely associated with Thomas Edison in charge of engineering problems. It was he who made all the drawings for the structure, crane, and location of boilers, engines and switchboards of the First District Pearl Street Station—a pioneer job, as it was the first steam-operated central station in the United States. He designed central stations for construction in Chile and in Canada. He installed and operated the generating plants for Edison at the Louisiana Exposition in 1884 and at the New Orleans Exposition the following year. At the age of twenty-six he became vice-president and general manager of the Westinghouse Electric Co., and a little later president of the Northwest General Electric Co. On January 1, 1902, Colonel Byllesby organized the corporation of H. M. Byllesby & Co., of which he was president and active head at the time of his death.

In addition to being president of this company he was an officer and director in public-utility concerns, principally gas and electric, all over the United States.

From the first month of the War Colonel Byllesby devoted much time to the interest of the Entente. He was one of the few men who, from the beginning of the war, correctly visualized the tremendous issues involved. From August, 1914, until the entrance of the United States into the conflict, he was very active in platform and organization work, and, beginning April 6, 1917, he gave his entire time to the service of the Nation.

Despite his age of sixty, Colonel Byllesby served during the War as general purchasing agent of the A.E.F. and in this capacity was stationed at London. When he was honorably discharged in 1918 he was awarded the Distinguished Service Order by the British Government and later received the American Distinguished Service Medal. The latter citation stated that he "displayed great energy, a comprehensive knowledge of large business affairs and executive ability of the highest order," and that "by his broad experience, foresight and splendid ability to coöperate with the representatives of our Allies, he solved many difficult problems of fuel supply with conspicuous success and in a manner which insured, at critical times, a plentiful supply of coal, both for our transport service and our troops in France, thereby rendering services of great value to the American Expeditionary Forces."

Colonel Byllesby was one of the very early members of The American Society of Mechanical Engineers, joining the organization in 1882. He was a fellow of the American Institute of Electrical Engineers, a member of the American Society of Civil Engineers, the Western Society of Engineers and the National Electric Light Association. He belonged to the Union League and University Clubs of Chicago, and to the Metropolitan, Bankers, Railroad and Lawyers Clubs of New York.

Present and Future Power Requirements of New England

THE power facilities and possible sources of further power supply in New England are the subject of a report recently made by a committee appointed by the Associated Industries of Massachusetts in March, 1923. The committee is made up of Charles T. Main, Past-President A.S.M.E., Chairman; Henry I. Harriman, President New England Power Company; Dugald C. Jackson, Professor of Electrical Engineering, Massachusetts Institute of Technology; George L. Finch, Power Superintendent of the Hood Rubber Company, Secretary; and B. Preston Clark, Vice-President of the Plymouth Cordage Company.

The report presents a statement of the present power requirements of New England industries and the probable growth of these requirements during the next ten years. It touches on the possibilities of railroad electrification and on the geographical distribution of power requirements, the available sources of water power, the possibility of procuring power from Canada, and the interconnection of large water-power and steam plants. The general conclusions of the report are abstracted below.

The industries of Massachusetts required in 1922 for their load of about 1,250,000 hp. a total installed capacity of about 1,800,000 hp. Of this, about 300,000 hp. was steam-generating capacity in industries which required considerable steam for process work as well as for power.

The total energy used in New England in 1922 (except in steam locomotives) was about 7,500,000,000 kw-hr., of which about one-half was generated by the industries themselves and the other half by the public utilities. Of this total in the neighborhood of 2,200,000,000 kw-hr. was generated by water power. . . . .

Judging from the past, the indications are that the total power requirements for New England ten years hence will be at least 15 per cent and possibly 20 per cent more than they are now. The same relative increase will hold for Massachusetts alone.

It is expected that on an average for the next ten years the load on the public utilities will increase each year by the following amounts, which may be regarded as a conservative estimate:

For the Massachusetts-New Hampshire-Rhode Island group centering around eastern Massachusetts 90,000 kw. net additional capacity will be required and 190,000,000 kw-hr. generated; for all New England 140,000 kw. and 300,000,000 kw-hr.

This would mean that during the next ten years approximately 1,400,000 kw. of central-station capacity must be added to that already existing in New England, in addition to replacements.

To electrify the additional railroad trackage, on which electrification would be desirable in the near future, would require about another 1,000,000 kw. of station capacity and 2,000,000,000 kw-hr. per year after the electrification is accomplished. Such electrification of the railroads will depend upon their financial condition.

The question before us, and which we are now considering, is where can the necessary increase in power be obtained at reasonable costs.

There is undeveloped water power in New England at sites where 1000 hp. or more is available for 60 per cent of the time, about 860,000 hp. or 640,000 kw. If it could all be fully developed for 50 per cent load factor this would require a station capacity of 1,720,000 hp. or 1,280,000 kw., and would produce about 4,830,000,000 kw-hr.

This would be sufficient to take care of the requirements for several years, not considering the electrification of railroads, but unfortunately about three-quarters of this undeveloped power is in Maine, and under the existing laws cannot be exported. There remains in the rest of New England about 160,000 kw., equivalent to about 1,200,000,000 kw-hr. Most of this power will not be developed in the near future because of the high cost of the development and of delivered current.

It appears that in all New England, including Maine, enough could be developed at reasonable cost to produce about 3,000,000,000 kw-hr., and of this only a small portion is in the Massachusetts-New Hampshire-Rhode Island district, the area with which this report is mostly concerned. The balance (requiring interstate transportation) is not available in the absence of legislation, or Supreme Court ruling, declaring electric power to be a lawful article of commerce.

The total from all such sources is relatively small compared with the total power requirements for New England's growth, although important to individual plants.

In view of the above, it appears that the great bulk of the power for New England's additional requirements, particularly in the district centering about eastern Massachusetts, must come from the following:

(*a*) Large public-service steam plants, located not far from the load centers and so as to obtain coal at the lowest rates, and containing large units and interconnected so as to run on high load factors at minimum operating cost; or

(*b*) A supplementing of such steam plants in New England by large water powers in Canada, if proper agreements can be made for the export of electric current.

There are two potential sources of such water power, the large developments on the tributaries of the St. Lawrence in Quebec, in the early construction of which private capital is already engaged, and which can be economically developed in progressive steps; and the still larger developments on the St. Lawrence which undoubtedly must wait for the international canalization of the river.

Broadly considered, the development of water powers as fast as the load is created to absorb their output is highly desirable as a measure of conservation of irreplaceable fuel resources. Nevertheless, these developments must be justified from the economic standpoint before they can attract the necessary capital.

Taking a broad view of the demands that will be made in the near future upon every available resource for transportation and power, it is merely a question of time before the St. Lawrence canal will be constructed. It is possible that permanent power from this source may be available for New England by 1935 or 1940.

In the meantime, it is to the mutual advantage of both New England and Quebec to promote for their joint use the early development of some of the water powers on the tributaries of the St. Lawrence. The crowded industrial centers in southern New England need this water power which now runs to waste, and the domestic plants and paper industries of Quebec look to this side of the border for their essential coal, the cost and difficulty of securing which is continually increasing.

The inference should not be drawn from comparisons of cost that have been made in the report that it is possible for water power to free the industries from their dependence upon a supply of coal; it can merely prevent the cost of power from mounting to continually higher levels, and it can lessen the hazard due to interruptions of the coal supply. If such water power were to be imported in competition with (instead of supplementary to) any and all steam power, its load factor would be reduced and its cost increased above that shown in the estimates.

The hourly load requirements of industries are so variable that even when tied together in large power systems the annual peak load is two and one-half times the average load. Water power from a distant source will best serve New England by being transmitted at as uniform a rate as possible, that is, on a high load factor, and delivering as much surplus power as can be absorbed by the shutting down of steam-driven units while water is wasting over the dams. Hence, such imported water power will be used to supplement the steam power, and one of the principal uses of the near-by steam plants will be to take the load peaks in regular and stand-by service. Very few steam-driven units will be run at night with these large supplementary water powers available. The steam load factor, or hours of operation, is bound to be less and the water load factor more than for the average power demand.

Both the size and character of New England's load requirements will continue to demand fuel to burn for a large part of the load. It is to be expected that the interconnection of large water-power and steam plants will result in dismantling only the smaller and less efficient steam plants.

Finally, central-station power, distributed by large interconnected systems, is the logical source of supply for over three-quarters of our growing industrial load. The cost of this power can be kept from steadily increasing only by the early importation of water power capable of relieving fuel-burning stations of a large share of the base load.

Dimensioning with Tolerances

ON THE occasion of the presentation of his paper on Some Limitations on Manufacturing to Close Limits at the Machine Shop Meeting in Philadelphia on March 25, B. H. Blood read a set of rules for dimensioning with tolerances which had been prepared by Earle Buckingham. The interest that was manifested in these rules by those who heard them presented has led to their publication below.

RULES FOR DIMENSIONING WITH TOLERANCES

1 There is but one dimension in the same straight line that can be controlled within fixed tolerances. That is the distance between the cutting surface of the tool and the locating or registering surface of the part being machined. Therefore it is incorrect to locate any point or surface with tolerances from more than one point in the same straight line.

2 Every part of a mechanism must be located in each plane. Every operating part must be located with proper operating allowances. After such requirements of location are met, all other surfaces should have liberal clearances.

3 Dimensions should be given between those points or surfaces which it is essential to hold in a specific relation to each other. This applies particularly to those surfaces in each plane which control the location of other component parts. Many dimensions are relatively unimportant in this respect. It is good practice in such cases to establish a common locating point in each plane and give, as far as possible, all such dimensions from these common locating points. The locating points on the drawing, the locating or registering points used for machining the surfaces, and the locating points for measuring should all be identical.

4 The initial dimensions placed on component drawings should be the exact dimension, that would be used if it were possible to work without tolerances. Tolerances should be given in that direction in which variations will cause the least harm or danger. When a variation in either direction is equally dangerous, the tolerances should be of equal amount in both directions, or bilateral.

5 The initial clearance, or allowance, between operating parts should be as small as the operation of the mechanism will permit. The maximum clearances should be as great as the functioning of the mechanism will permit.

Engineering and Industrial Standardization

Standardization of Tee Slots of Machine Tools Now in Progress

A SUB-COMMITTEE was recently organized to develop standard dimensions for tee slots of machine tools. This is the first of the four tool-holding and work-holding machine elements, the standardization of which was decided some little time ago by the Central Committee on the Standardization of Small Tools and Machine Tool Elements. This activity is sponsored by the National Machine Tool Builders' Association and The American Society of Mechanical Engineers, and it is expected that the organization of sub-committees to take up each of the sub-projects will follow in rapid succession.

The Sponsor Bodies placed before the sub-committee a large amount of data on tee-slot standardization which had been collected, and this material was handed to a working committee which immediately began a study of it together with other available data. An open meeting of this Working Committee was held during the Spring Meeting at Cleveland.

National Standardization—What It Is Accomplishing for Industry

"STANDARDIZATION is today the most important approach to greater industrial efficiency. The magnitude of the yearly savings to be made is almost incredible; they are to be measured, as Secretary Hoover has said, 'in hundreds of millions and billions of dollars.' Actual savings that are now being made in the automobile industry through organized standardization activities are estimated by the industry itself at 750 million dollars a year; it is these savings which have made the automobile generally available instead of its being only a luxury for the rich."

The above paragraph is the opening statement in a twenty-four page pamphlet recently issued by the American Engineering Standards Committee. After touching on the social and economic significance of this fundamentally important instrument in our modern life, this monograph discusses briefly standardization during the war and in time of peace.

Part II is entitled Three States of Standardization; (*a*) within the factory, (*b*) within the industry, and (*c*) national standardization. These phases of the subject are presented in part as follows:

> Every industrial plant is carrying on standardization of its own products and processes and its competitive success largely depends upon the cleverness and thoroughness with which it has studied and solved these problems. Standardization within the plant has been the essential factor in the development of mass production, and mass production in turn has been the chief contribution of the United States to the development of industry.
>
> Company standardization, which had its greatest growth during the last half of the nineteenth century, gave rise to collective standardization for entire industries. Such standardization by industries, carried on by technical societies and trade associations, has for the most part been a product of this century. The adoption of a standardized track gage and of a system of interchangeable brakes and couplings was a necessary step in the development of our railroad system, and upon this in turn rests our whole economic and industrial structure.
>
> Just as standardization by individual companies led to standardization by industries so standardization by industries has in turn led to national standardization among industries as a whole, technical societies and trade associations here playing the same roles as the individual companies in industry standardization.
>
> This development has been due to the fact that most standardization projects transcend the limits of a single industry. If the machine-tool builders, working independently of other users, were to draw up specifications for the various classes of steels which they need they would be paralleling the work that is being done by a score of other industries whose needs are similar and to a large extent identical. The steel-consuming industries working independently would confront the manufacturers with a medley of conflicting requirements. This would be reflected in higher prices, slower deliveries, and poorer materials than would be the case if steels were standardized on a national basis.
>
> Standardization cannot reach its greatest effectiveness until it is treated as a national problem; this has been recognized by the leading industrial countries and they have found it necessary to establish national standardizing bodies. Just as company standardization was a dominant characteristic of the last century, just as industry standardization was a dominant characteristic of the present century, so national standardization will prove to be a dominant characteristic of the present and of the future.

Not only are the national technical societies, the trade associations, and commercial organizations such as the Chamber of Commerce of the United States either carrying on or promoting standardization activities for their members, but the United States Government, which represents all interests, is doing a very important work in this direction. The various branches of the Federal Government that are active in this field are mentioned and then the author goes on to draw the following conclusion:

> But with all these interests, the individual company, the trade association, the commercial organization, the technical society, state and local governments and the Federal Government, actively concerned with standardization still something more was needed. In fact it was the very existence of so many different interests that created the need for some way of bringing them together in the systematic coöperation upon which standardization must rest, some means of establishing a procedure under which they may work and under which national standards may be formed, and finally of deciding when a standard so formed shall be judged worthy of being recognized as an American Standard.
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> For this purpose nothing less than a national clearing house will serve, an organization so thoroughly representative of all interests, so democratic in its procedure, so sensitive to the requirements of complete coöperation, that it can carry on the work with acknowledged authority, so that the standards thus established will be generally accepted as in reality national standards. Neither government nor industry alone can perform this function; it must be a coöperative undertaking.
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> The initiative in forming such a clearing house was taken by five national engineering societies in 1917. Then after two years of lively discussion among the many interested bodies, an organization was established under the name of the American Engineering Standards Committee.

The third and last section of this interesting little book consists of a brief but comprehensive description of the American Engineering Standards Committee and the procedure it has adopted. Here we find many interesting paragraphs, a few of which are quoted below:

> The members of the American Engineering Standards Committee are nine national engineering societies, seven departments of the government and nineteen national associations representing most of the industries of the country.
>
> This is the agency which is primarily responsible for carrying standardization over to the third or national stage. Through its methods and procedure the work of the hundreds of bodies that are in the standardization field is being broadened and unified into a truly national system.
>
> The A.E.S.C. is the authoritative channel of coöperation with similar bodies in foreign countries; two international conferences of secretaries have been held, and there is a regular interchange of information on the status of all projects in hand. In fact a fourth stage of standardization, international standardization, is slowly coming into being. This development is of particular importance to foreign trade and will attain still greater importance in the future.
>
> One practical result of the complete coöperation with the Government is a group of forty national industrial safety codes. This program was undertaken in order to assist the state industrial commissions in bringing about a larger degree of uniformity in safety provisions and in placing the work on a sound engineering basis.
>
> Standardization like any other powerful tool is dangerous if misused; it may be begun too early, it may be carried too far, and it may be applied to improper fields. It is peculiarly important, with the rapidly growing interest in the practical use of standardization, that some one should be responsible for seeing that development takes place along right and reasonable lines. Standardization if wrongly used will produce a fixity and rigidity that will impede progress; but if rightly used it will vitalize and quicken industry; for it will release the mind and imagination from the pressure of unessential detail and the tedium of meaningless variety and give the opportunity for new advances.

The purpose of this booklet is to interest American firms in a plan of permanent financing of the A.E.S.C. through a system of sustaining memberships. The schedule of recommended annual subscriptions for such memberships is determined roughly upon a basis of one cent per $1000 of gross annual income, with a minimum of $25.

Library Notes and Book Reviews

THE Library is a coöperative activity of the A.S.C.E., the A.I.M.E., the A.S.M.E. and the A.I.E.E. It is administered by the United Engineering Society as a public reference library of engineering and the allied sciences. It contains 150,000 volumes and pamphlets and receives currently most of the important periodicals in its field. It is housed in the Engineering Societies Building, 29 West 39th St., New York, N. Y. In order to place its resources at the disposal of those unable to visit it in person, the Library is prepared to furnish lists of references to engineering subjects, copies of translations of articles, and similar assistance. Charges sufficient to cover the cost of this work are made.

The Library maintains a collection of modern technical books which may be rented by members residing in North America. A rental of five cents a day, plus transportation, is charged. In asking for information, letters should be made as definite as possible, so that the investigator may understand clearly what is desired.

L'Analysis Situs et La Geometrie Algebrique. By S. Lefochetz. Gauthier-Villars et Cie., Paris, 1924. Paper, 6 × 10 in., 154 pp., 20 fr.

This monograph on Analysis Situs forms one of a series on the theory of functions issued under the editorship of Emile Borel, of the Institut de France. It is partially based on a series of lectures given in Rome, in 1921, under the auspices of the Institute of International Education, and on investigations carried out, shortly before that time, under the auspices of the American Association for the Advancement of Science.

Cargo Handling at Ports. By Brysson Cunningham. John Wiley & Sons, New York, 1924. Cloth, 6 × 9 in., 180 pp., illus., diagrams, tables, $3.50.

While there are a number of excellent treatises on the mechanical handling of material, the literature on the specific problems met with in transferring material between ship and shore is scanty and scattered. The present volume deals with this question and is an attempt to define and coördinate the principles underlying the cargo-handling practices that prevail at different ports throughout the world. The book omits questions of management, documentation, and accountancy, and confines itself to the engineering or mechanical side of the matter.

Cost Accounting Fundamentals. By L. T. Konopak. Ronald Press Co., New York, 1924. Cloth, 6 × 9 in., 235 pp., $3.

The present work is intended to present the subject as a whole and indicate its bearing upon management, so that the business executive may grasp fully the significance of cost accounting in relation to his own duties, and the cost accountant perceive the ultimate purpose of his work. To this end the discussion is confined to the larger, more significant facts, and the illustrations are freed from details The conditions discussed are those found in factories of medium size.

Factory Management. By Henry Post Dutton. Macmillan Co., New York, 1924. Cloth, 5 × 8 in., 329 pp., illus., charts, tables, $2.75.

In this work the author attempts to give a balanced description of the operation of the several departments of a factory and to show their relation to each other and their problems as part of the greater problem of coördinating all the activities of the organization toward the accomplishment of a single purpose. The book is an effort to collect the different theories and methods of production control and form from them a connected philosophy of control. The author tries to present the viewpoint of the owner and manager, as well as that of the specialist.

Fundamentals of Radio. By James L. Thomas. D. Van Nostrand Co., New York, 1923. Cloth, 5 × 8 in., 207 pp., illus., diagrams, $1.50.

An elementary exposition of the theory underlying the operation of radio apparatus, intended as a textbook for operators and mechanics, both professional and amateur. The author avoids the use of mathematics, when possible, and explains matters in non-technical language.

Gyroscope; Its Practical Construction and Application. By P. P. Schilovsky. E. & F. N. Spon, London, 1924. Cloth, 6 × 9 in., 224 pp., illus., diagrams, tables, 14 s.

This volume is in three sections. The first treats of the mechanics of the gyroscope, discussing the three-framed and the two-framed gyroscope, the precessing spinning-top and gyroscopic systems of locomotion. Section two is devoted to monorail locomotion. The final section is a mathematical study of the theory of the monorail car, excerpted from the publications of P. T. Papkovitch. The author writes from the viewpoint of the inventor, in simple, non-mathematical fashion.

Interest as a Cost. By Clinton H. Scovell. Ronald Press Co., New York, 1924. Cloth, 5 × 8 in., 254 pp., $2.50.

Interest on investment may be included in the selling price of an article either as part of its cost or of the profit, if a business is to succeed. The present author considers interest a proper part of cost, and his book is written to present the reasons for this conclusion. The theory supporting his position is given, and the attitude of those in favor of it are set forth. The various objections to this view of interest are also given and answered specifically. The book should prove of interest to all students of cost accounting.

Ionen und Elektronen. By H. Greinacher. B. G. Teubner, Leipzig and Berlin, 1924. Paper, 6 × 9 in., 58 pp., $0.42.

A brief introduction to the subject, prepared to fill the need arising from the increasing industrial use of electron tubes. The author discusses volume ionization, the measurement of the ion flow, properties of ions, surface ionization, the law of free ions and the use of electron tubes.

Line Charts for Engineers. By W. N. Rose. E. P. Dutton & Co., New York, 1923. (Directly-Useful Technical Series.) Cloth, 5 × 9 in., 95 pp., tables, $3.

Intended to call the attention of engineers to the possibilities of charts as aids to calculation and especially to show how charts may be most easily made from formulas. Little knowledge of mathematics is required. The examples are taken from engineering practice. The greater part of the book relates to nomograms, but some examples of intercept charts are also included.

Taschenbuch fur den Maschinenbau. By H. Dubbel. Ed. 4. Julius Springer, Berlin, 1924. Cloth, 5 × 8 in., 2 v., illus., diagrams, tables, $4.30.

A concise work of reference for mechanical engineers, covering mathematics, mechanics, fuels, materials, machine elements, power plants, prime movers, hoisting and conveying machinery, machine tools, and electricity. Mathematics and mechanics are thoroughly treated, with special attention to principles, and with numerous examples of the practical use of important formulas. The practical part was prepared with special considerations of the machine designer and builder, to whom it gives a quick survey of those topics outside his special field and an acquaintance with the most important methods and numerical data. The book is the joint effort of a number of specialists.

Tulley's Handbook; Steam and Electrical. By Henry C. Tulley. Seventh edition, revised and enlarged by James F. Hobart. McGraw-Hill Book Co., New York, 1924. Cloth, 5 × 8 in., 3 vols., illus., diagrams, tables, $7.50.

A handbook for men engaged in the operation of power plants, as engineers, firemen, mechanics, etc. Explains the theory, construction, operation and maintenance of power-plant machinery in simple, practical fashion.